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(54) Abstract Title
Telemetry system in which data signals are modulated on power signals

(57) A telemetry system is capable of transmitting both power and data signals between a master unit 10 and at least one slave unit 50 (a,b) over a transmission system 12 which is part of a borehole, an oil well or a pipeline which may be a subsea installation. The transmission system comprises a tubing string or pipeline incorporating electrically isolating collars 200 a,b. A well casing or another pipeline may provide an earth/return path, the slave unit 50 being coupled between the tubing string and the well casing or between the two pipelines. The master unit 10 may use pulse width modulation of a power signal from driver 24 to send data to the slave unit 50. Power signals received by the slave unit are fed to regulators 56,58 to provide a local power supply for the slave unit. Data signals from the slave unit may be encoded by frequency shift keying at generator 64, synchronised with the pulses of the power signal, for transmission to the master unit. Data signals sent from the master unit may be detected by a timer circuit 70 and used to control valves, actuators or motors, while the data signals form the slave unit may represent the outputs of sensors. The data signals may be encrypted, e.g. using a Hamming code.

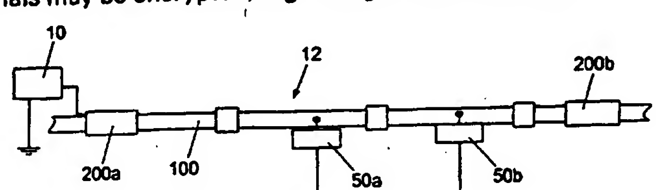

Fig. 2

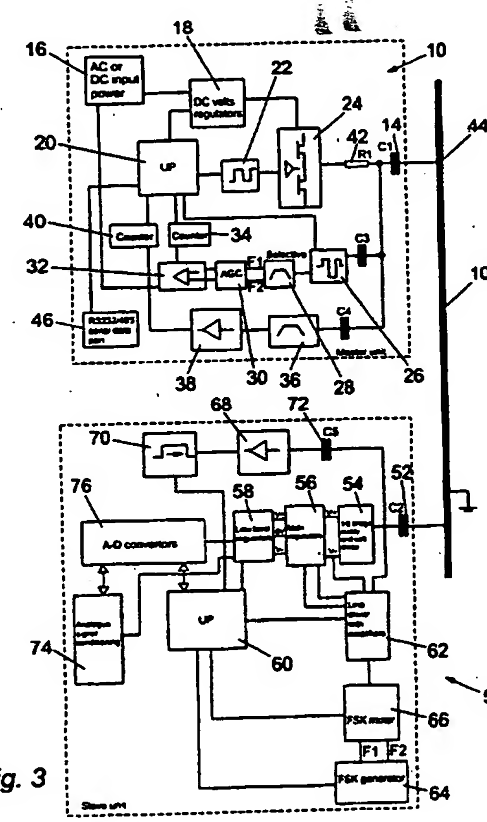

Fig. 3

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

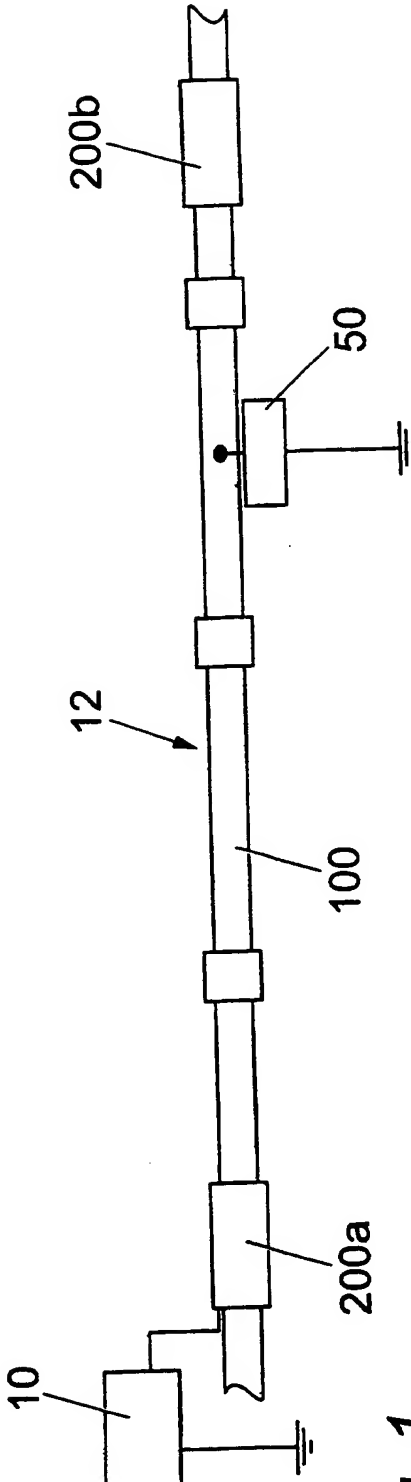


Fig. 1

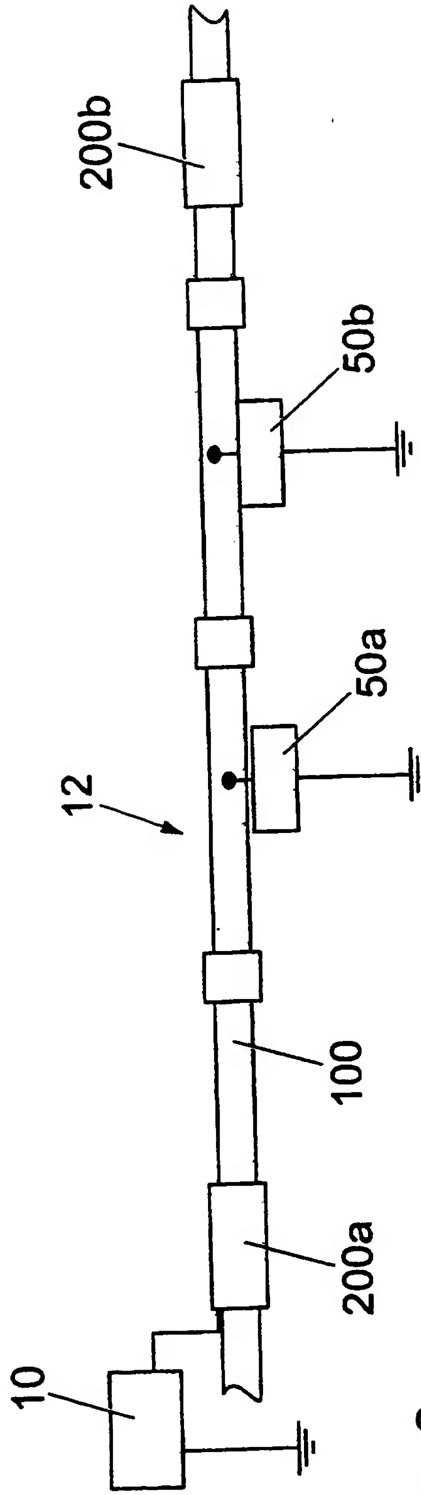
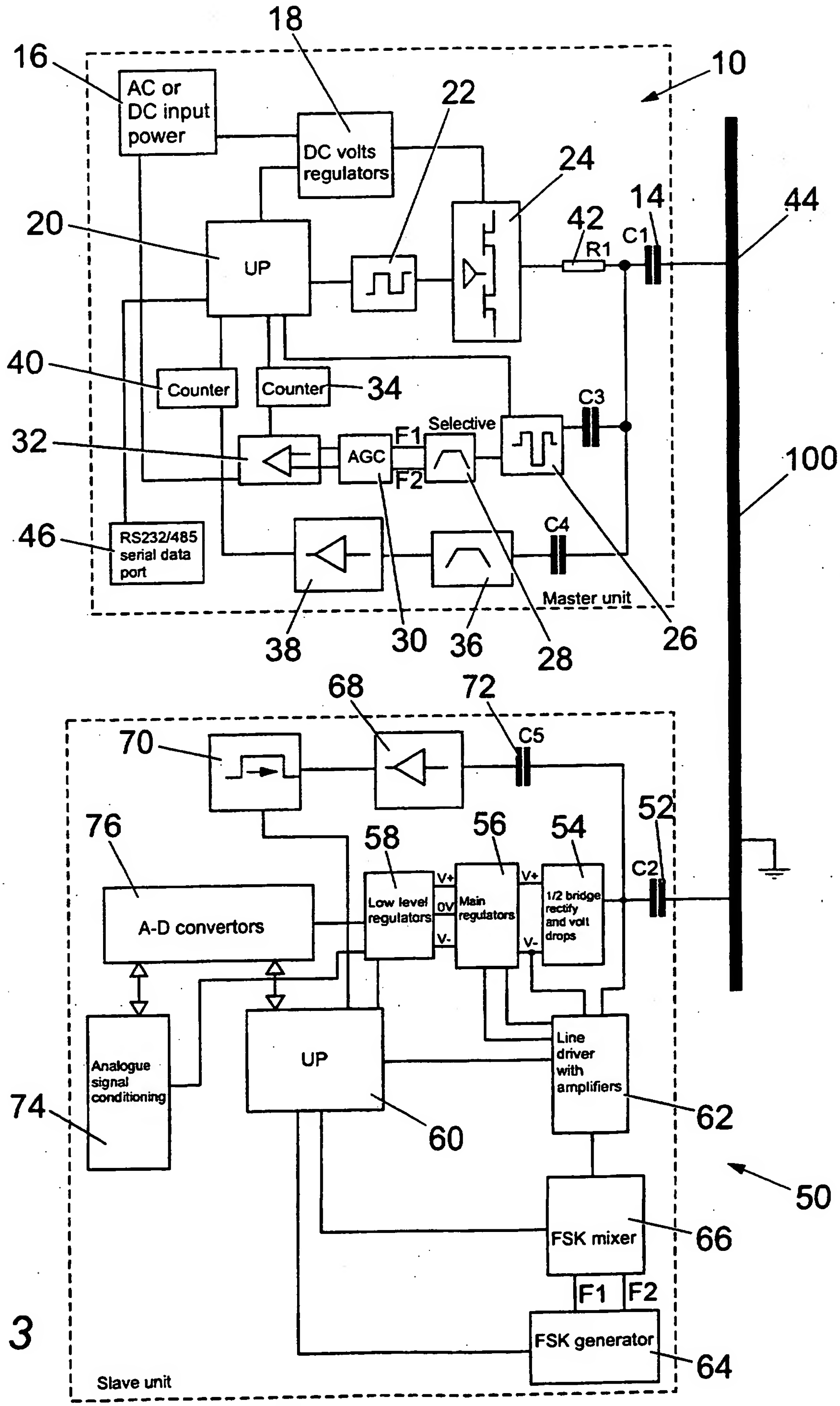


Fig. 2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AC or DC input power
18
DC volts regulators
22
24
10
14
42
R1
C1
44
20
UP
40
Counter
Counter
34
C3
32
AGC
F1
F2
Selective
100
46
RS232/485 serial data port
C4
Master unit
38
30
36
28
26
68
72
C5
70
76
58
56
54
52
C2
A-D convertors
Low level regulators
V+
0V
V-
Main regulators
V+
V-
1/2 bridge rectify and volt drops
Analogue signal conditioning
UP
Line driver with amplifiers
74
60
62
50
FSK mixer
66
F1
F2
FSK generator
64
Slave unit

Fig. 3

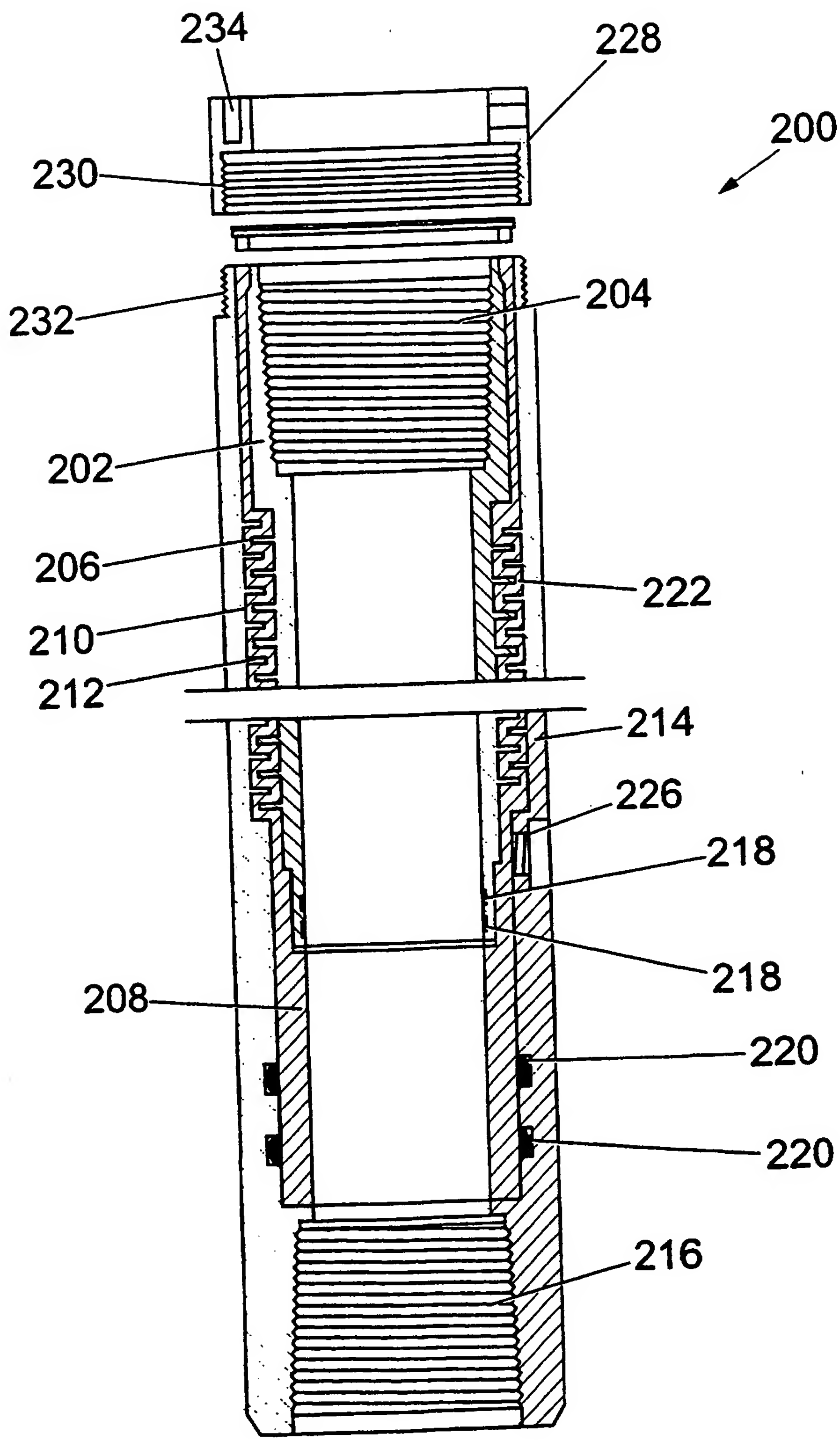
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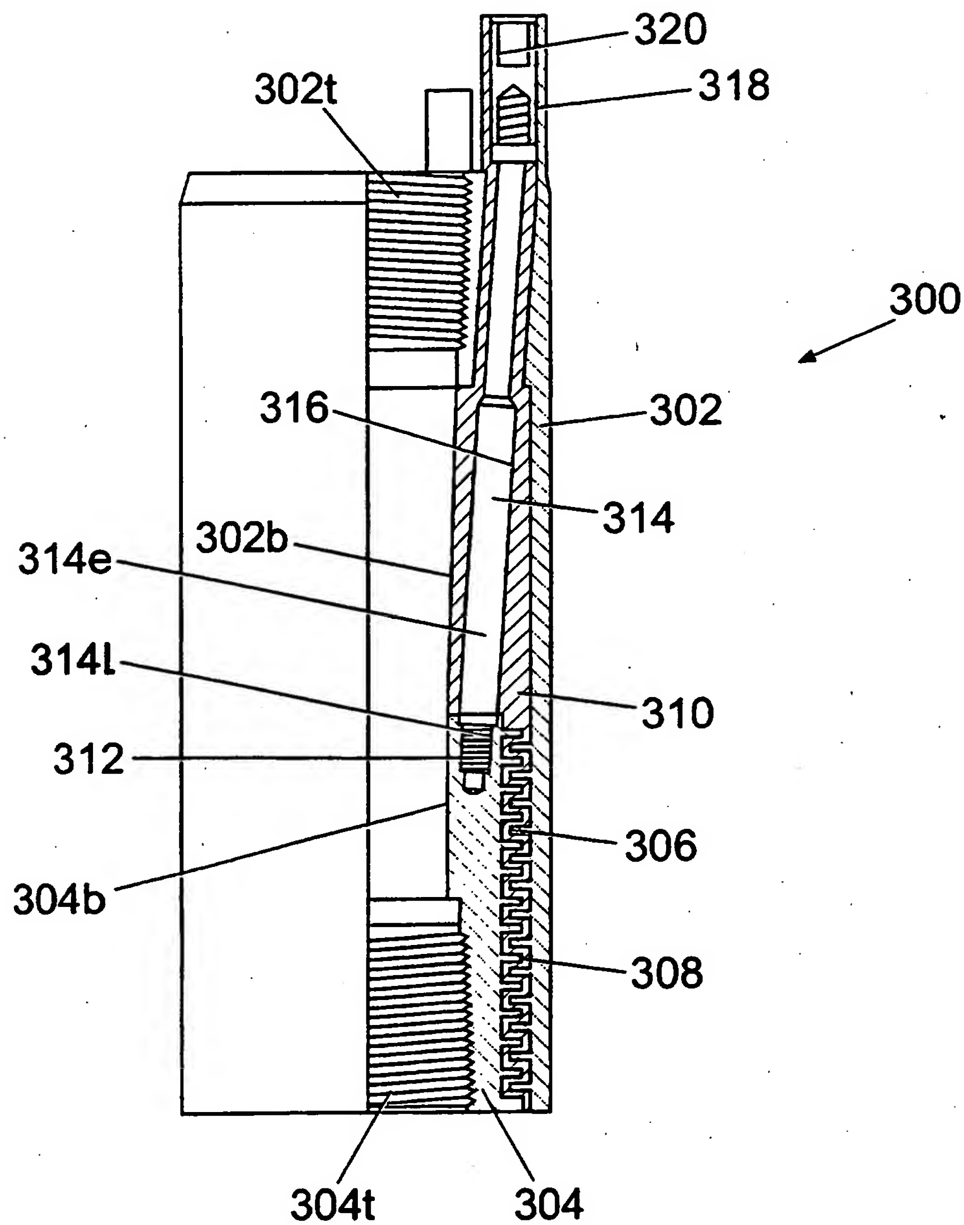
Fig. 4


320
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302t
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316
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302b
314e
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304b
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304t
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Fig. 5

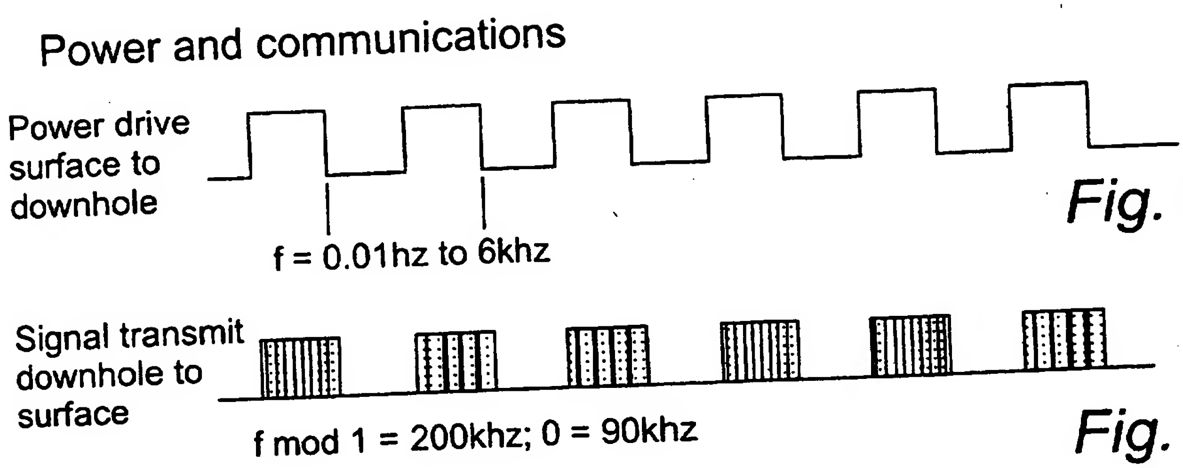


Fig. 6a

Fig. 6b

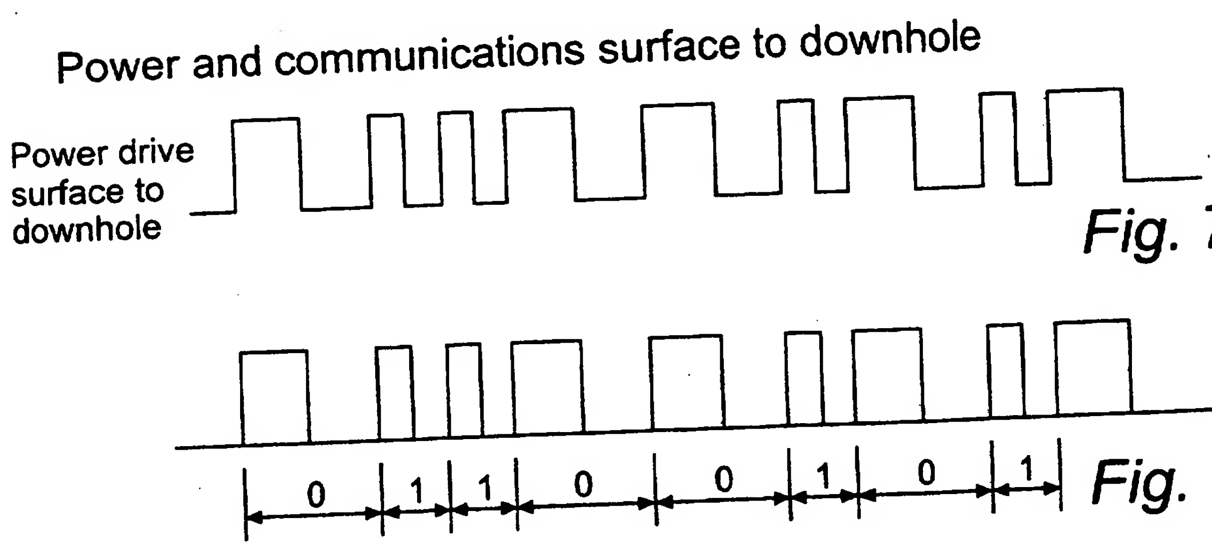


Fig. 7a

Fig. 7b

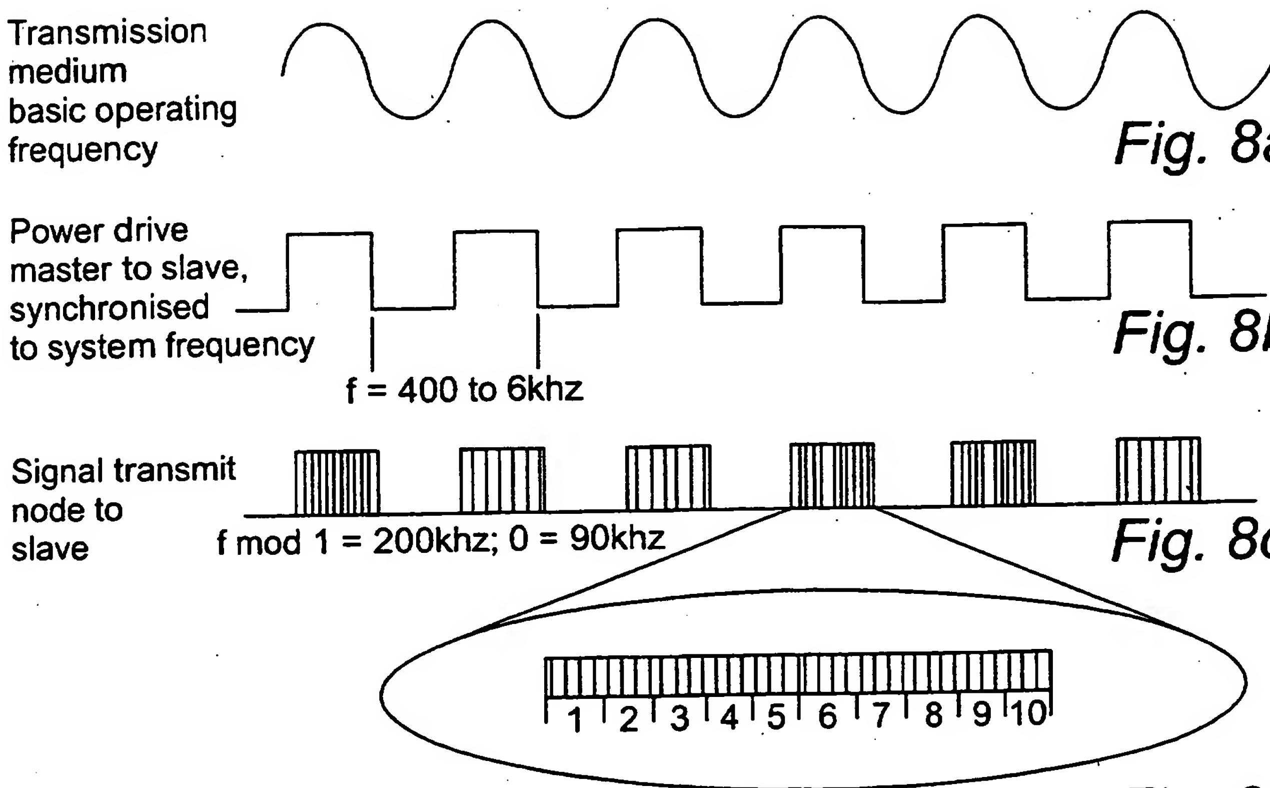
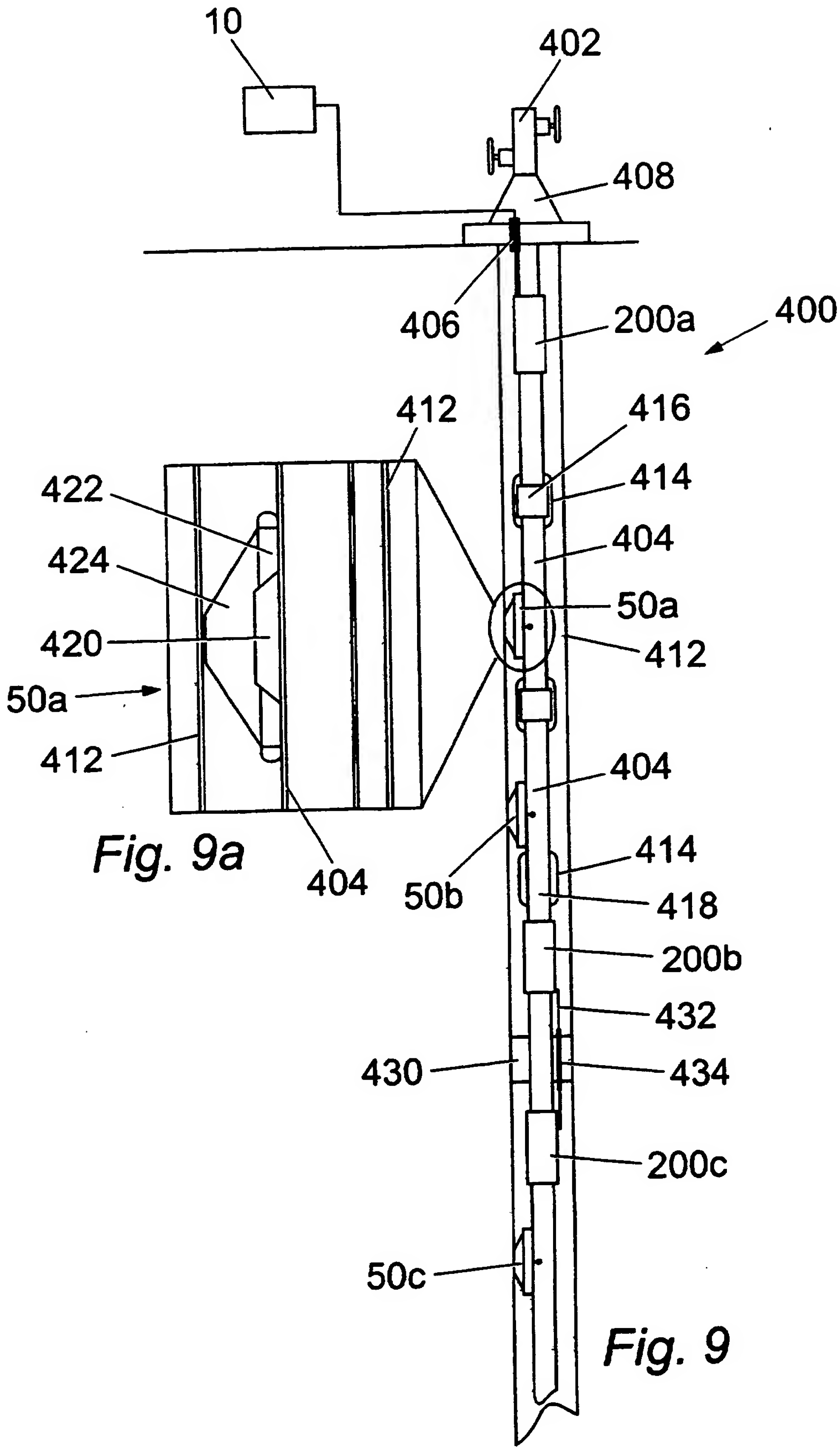


Fig. 8a

Fig. 8b

Fig. 8c

Fig. 8d


10
402
408
406
200a
400
412
416
414
422
404
424
50a
420
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50a
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404
50b
414
418
200b
432
430
434
200c
50c

Fig. 9a

Fig. 9

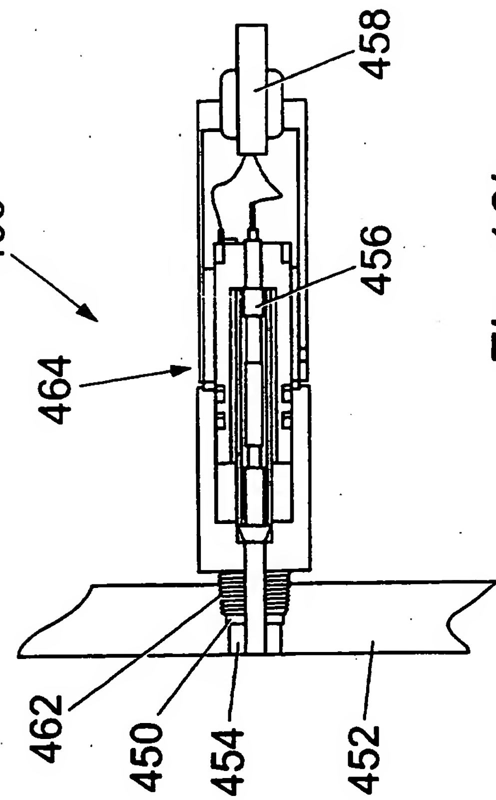

Fig. 10b

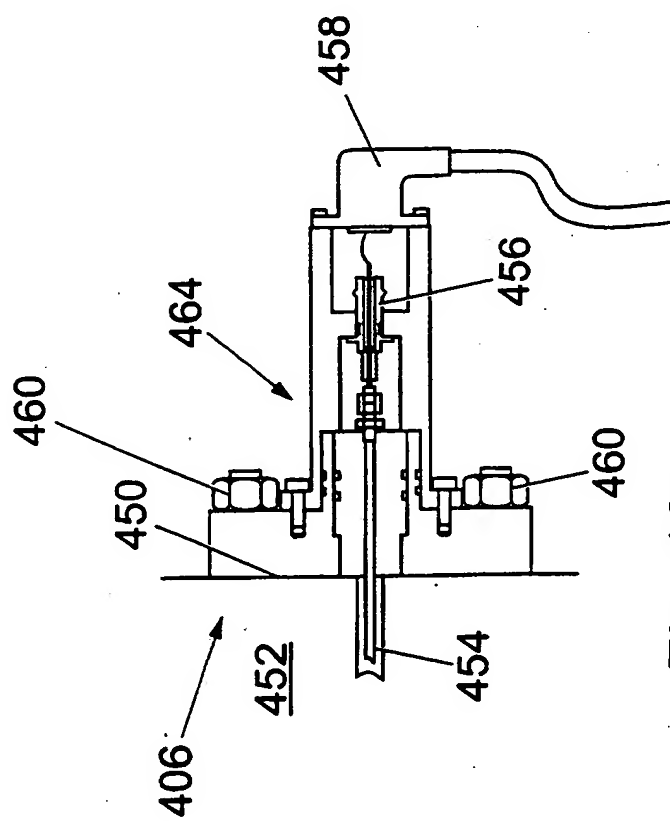

Fig. 10a

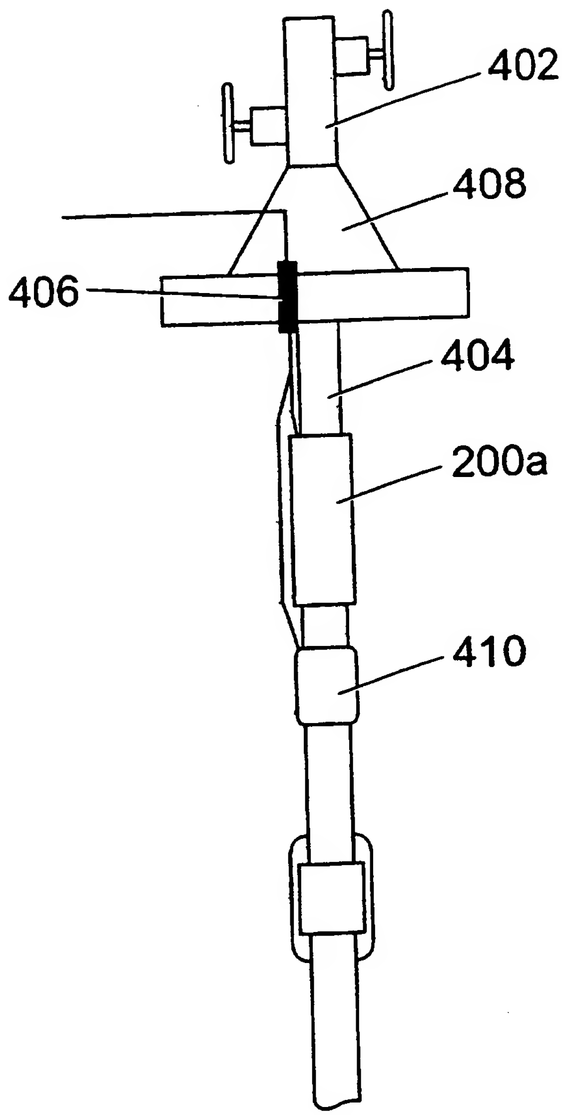

Fig. 11

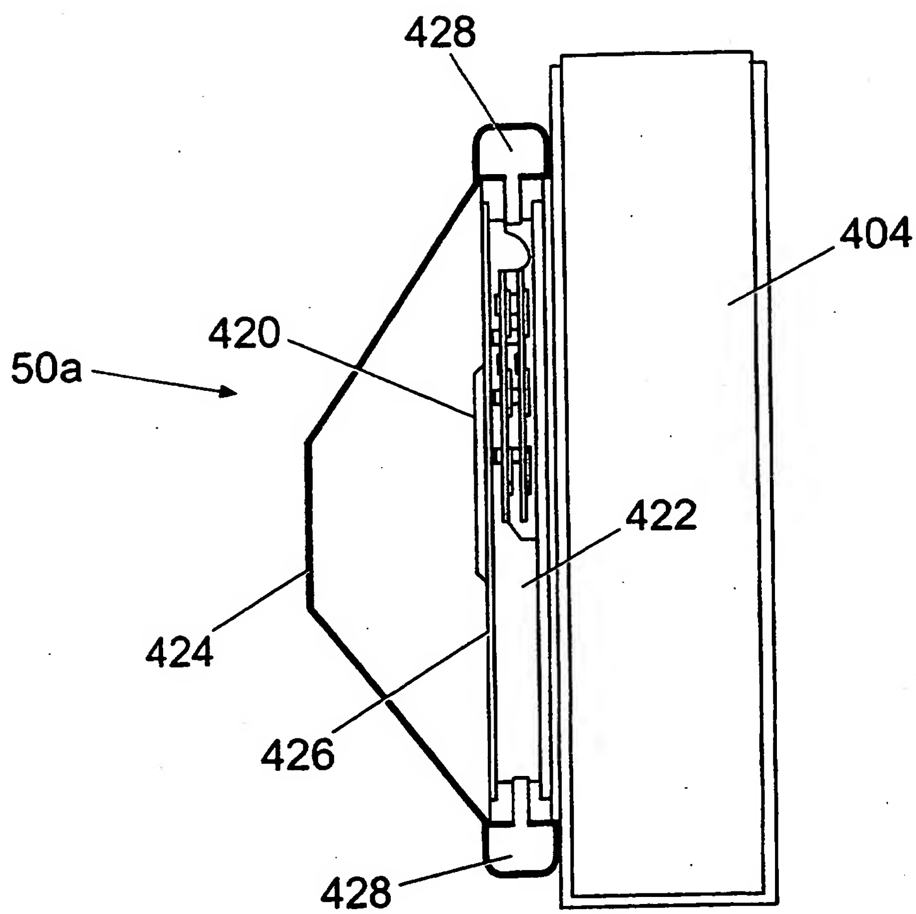

Fig.12

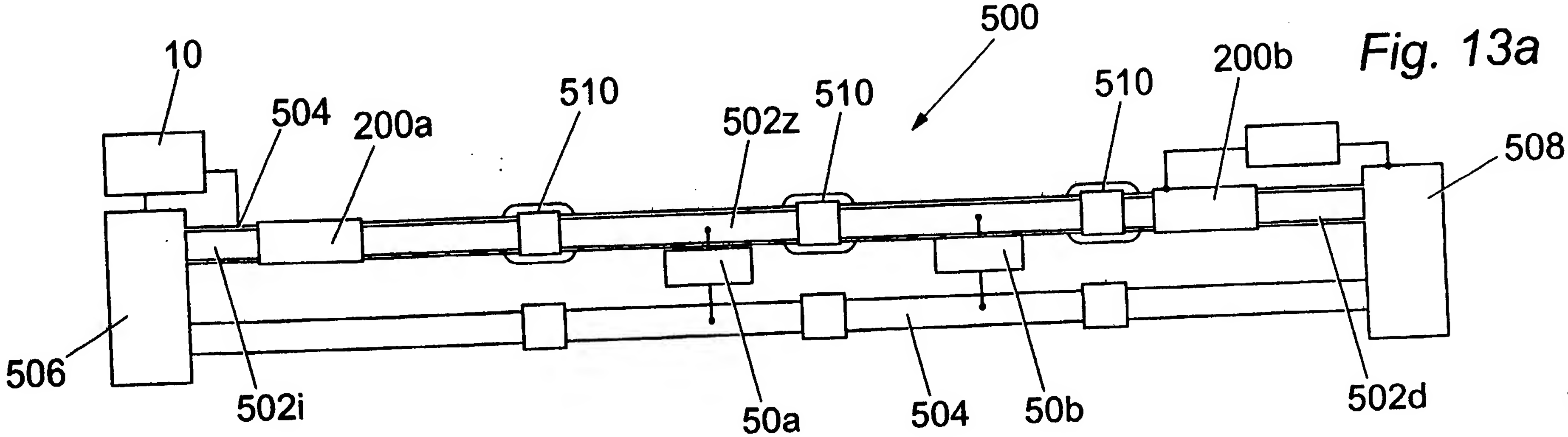

Fig. 13a

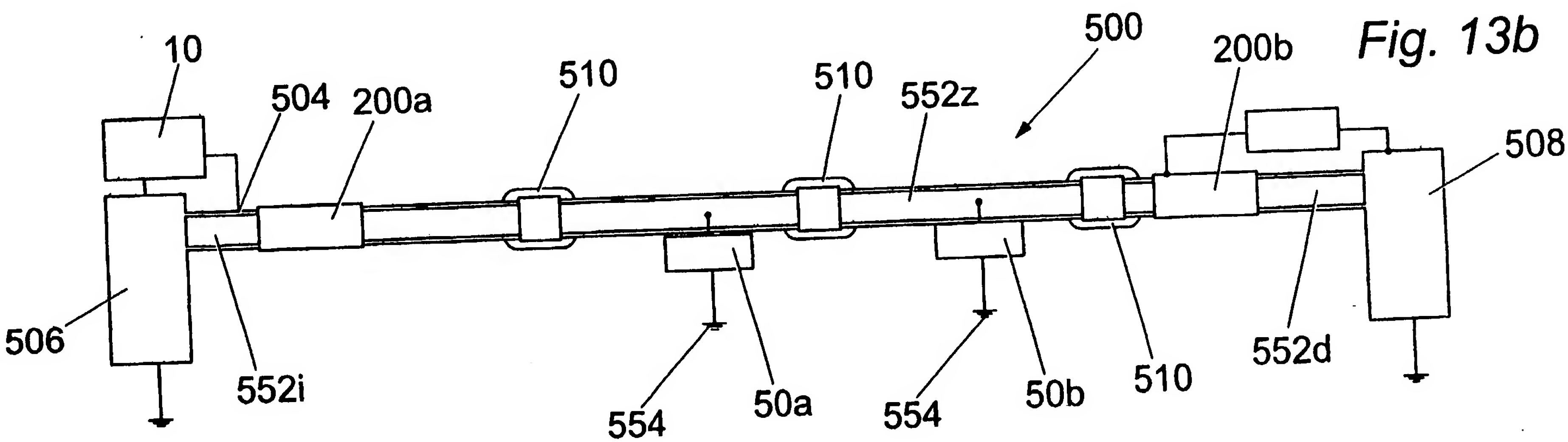

Fig. 13b

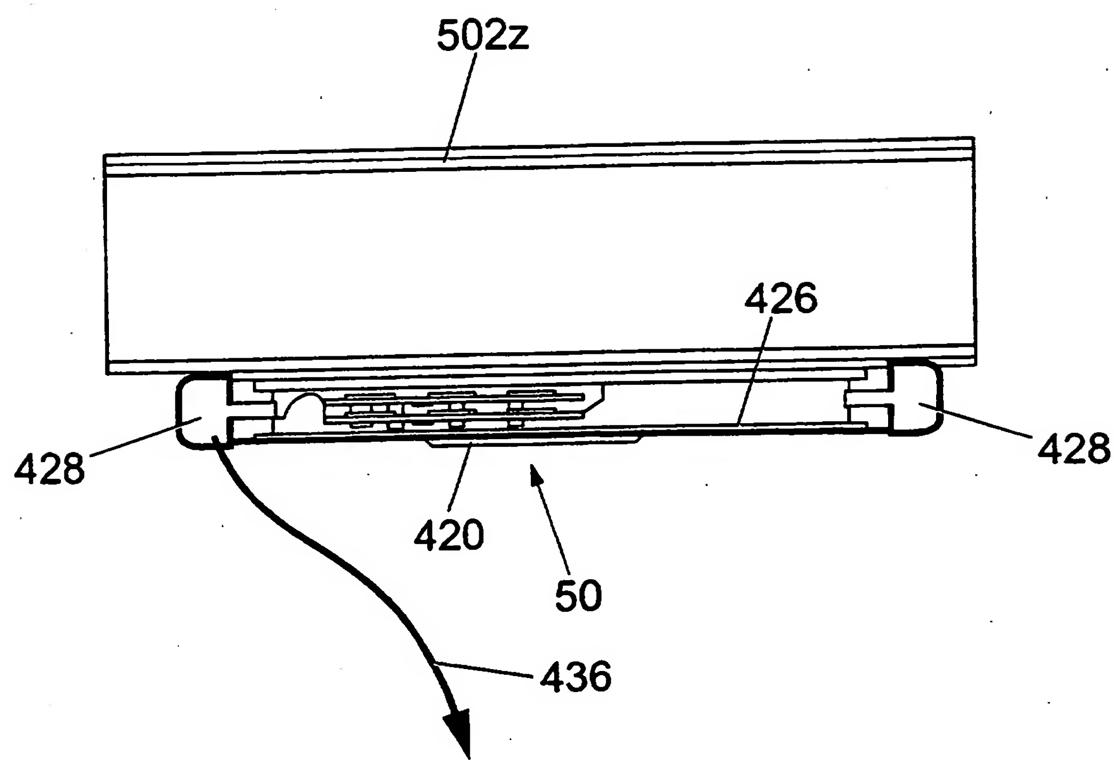

Fig. 14

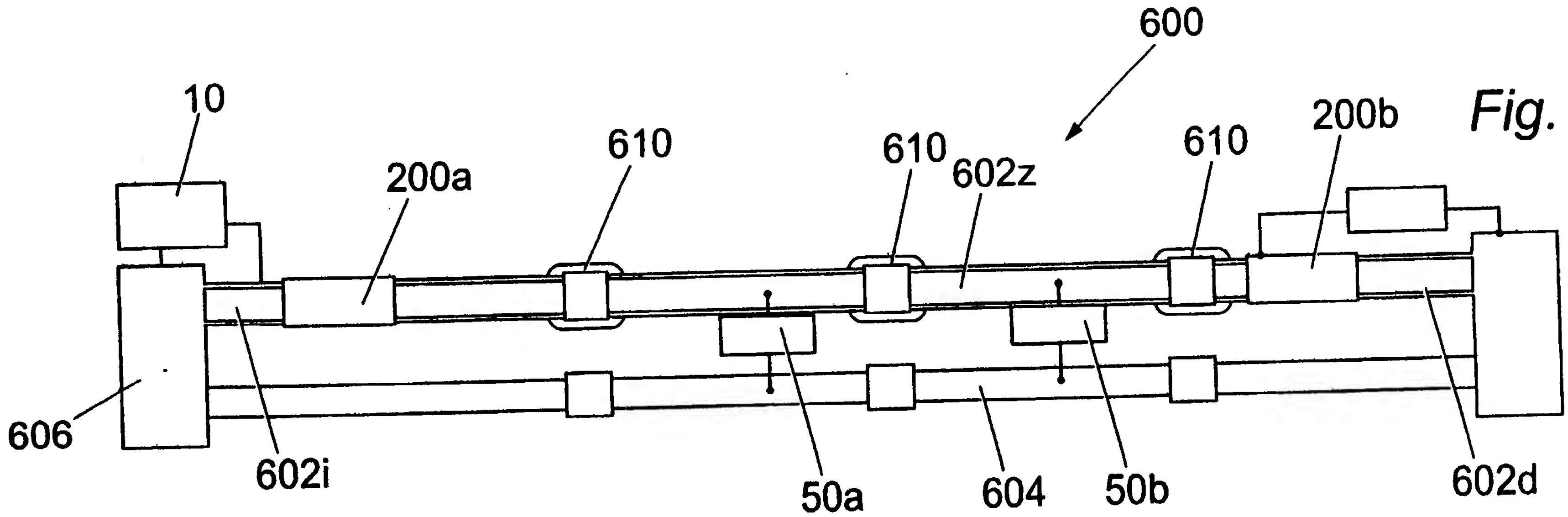

Fig. 15a

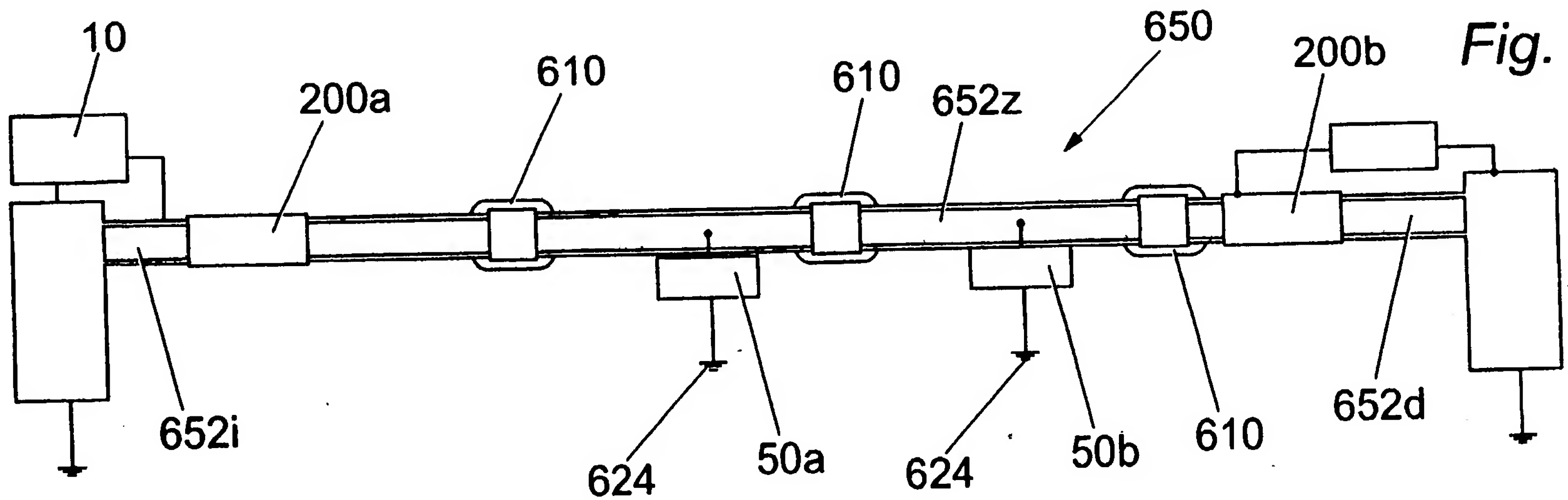

Fig. 15b

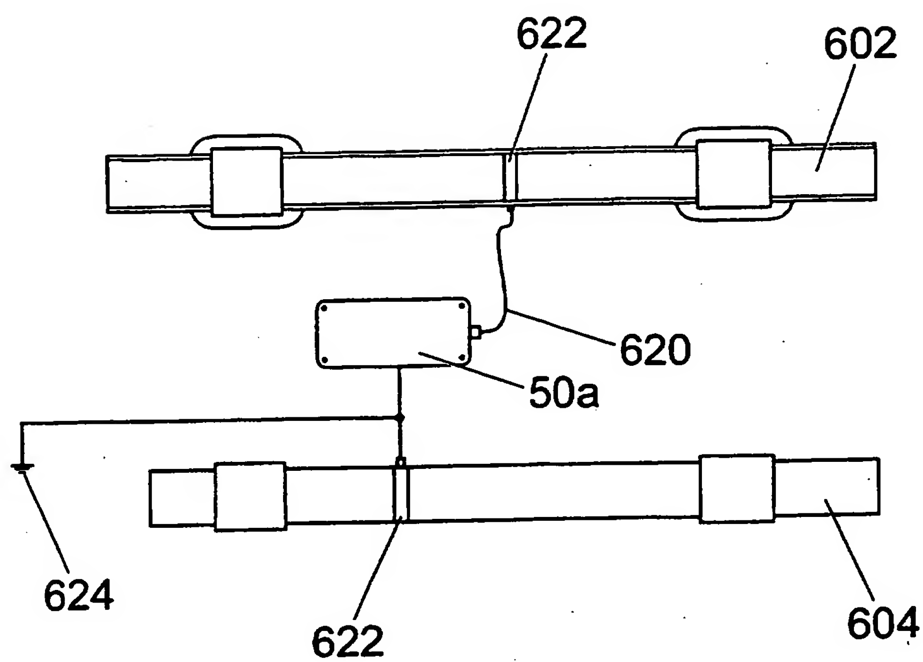

Fig. 16

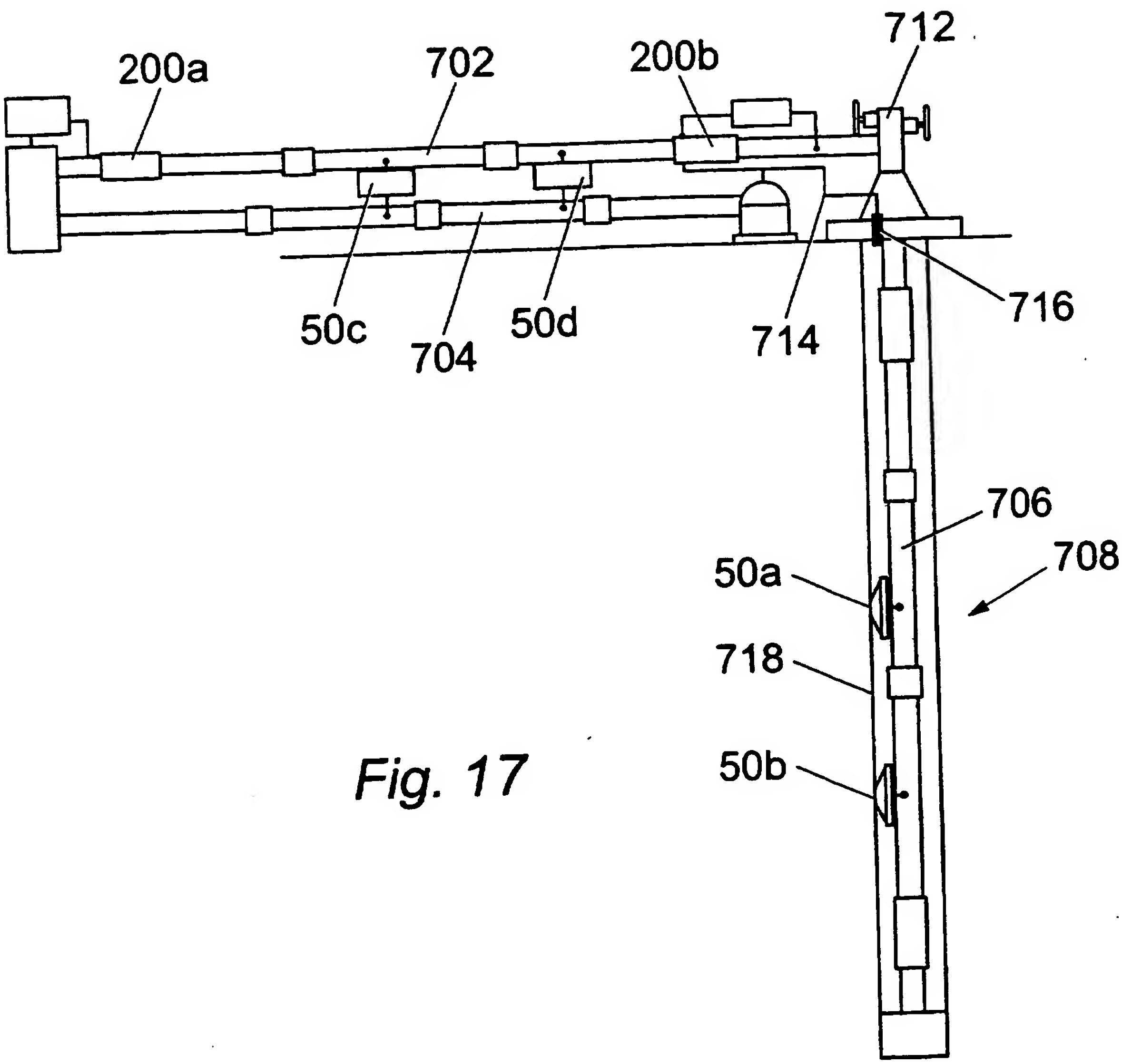

Fig. 17

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"Telemetry System"

The present invention relates to a telemetry system, particularly for use with an isolated pipeline or tubing string.

Telemetry systems are typically used in the oil and gas industry to transmit data from measuring devices, sensors or the like located downhole to receivers located at the surface. Conventional systems use transmission mediums such as drilling fluid or mud in which to transmit the signals between downhole and surface locations. In addition, mono-conductor instrument cables and single- or three-phase power cables are often used to transmit data communications in addition to their primary function.

Such conventional systems typically require at least two individual power sources: one at the surface to drive the receiving circuitry, and at least one

downhole to drive the remote circuitry. This duplication of power sources increases the cost of the system and may make the system unreliable, as more components are required.

Furthermore, the power source downhole has limitations associated with it in that the power output from the source is restricted due to the remoteness of the source. For example, the downhole power source may comprise batteries that have a limited power output and also a limited lifetime before they must be either replaced or recharged.

A typical production completion requires a mono conductor cable to be installed during the completion in order to recover signals or perform control of downhole devices. The installation of this cable creates cost and complexity in the completion design.

According to a first aspect of the present invention there is provided a telemetry system, the system comprising a master unit, and at least one slave unit remote from the master unit, the master and slave units communicating via a transmission system, wherein the telemetry system is capable of transmitting power and data transmissions between the units, and wherein the transmission system includes an at least partially isolated tubing string or pipeline.

According to a second aspect of the present invention, there is provided a method of transmitting power and data from a master unit to at least one slave unit remote from the master unit, the master and slave units communicating via a transmission system, the transmission system including an at least partially isolated pipeline or tubing string, the method comprising the steps of

generating a power transmission at the master unit;

generating a data transmission and synchronising the data transmission with the power transmission at the master unit;

transmitting the power and data transmissions via the transmission system to the slave unit; and

recovering the power and data transmissions at the slave unit.

According to a third aspect of the present invention, there is provided a method of transmitting data to a master unit from at least one slave unit remote from the master unit, the master and slave units communicating via a transmission system, the transmission system including an at least partially isolated tubing string or pipeline, the method comprising the steps of

generating a power transmission at the master unit and transmitting the power transmission to the slave unit;

recovering the power transmission at the slave unit;

generating a data transmission at the slave unit and synchronising the data transmission with the power transmission;

transmitting the data transmission via the transmission system to the master unit; and

recovering the data transmission at the master unit.

Optionally, the method may include the further steps of

dividing the data transmission into a series of sub-windows;

transmitting a specified data transmission from the slave unit to the master unit;

receiving the specified data transmission at the master unit;

determining which of the sub-windows reliably transmitted the specified data transmission.

The sub-windows that did not reliably transmit data are typically filtered out or ignored for subsequent transmissions. This technique may be used where the transmission system is particularly noisy or may be subject to interference and increases the chances of reliably retrieving data transmissions.

According to a fourth aspect of the present invention, there is provided a method of receiving and converting power and data transmissions sent from

a master unit to at least one slave unit remote from the master unit, the master and slave units communicating via a transmission system, the transmission system including an at least partially isolated pipeline or tubing string, the method comprising the steps of

receiving a power transmission at the slave unit;

dividing the power transmission into two channels;

rectifying and regulating the power transmission in a first channel; and

recovering the data transmission in a second channel.

According to a fifth aspect of the present invention, there is provided a method of receiving data transmitted by a master unit from at least one slave unit remote from the master unit, the master and slave units communicating via a transmission system, the transmission system including an at least partially isolated pipeline or tubing string, the method comprising the steps of

receiving the data transmission at the master unit;

filtering and conditioning the data transmission; and

regenerating the transmitted data.

Optionally, the method may include the further steps of

dividing the data transmission into a series of sub-windows;

transmitting a specified data transmission from the slave unit to the master unit;

receiving the specified data transmission at the master unit;

determining which of the sub-windows reliably transmitted the specified data transmission.

The sub-windows that did not reliably transmit data are typically ignored for subsequent transmissions. This technique may be used where the transmission system is particularly noisy and increases the chances of reliably retrieving data transmissions.

The pipeline or tubing string is typically electrically isolated using at least one isolating collar. The isolating collar typically comprises first and second connectors, the first and second connectors being threadedly coupled together. Preferably, an electrical isolating material is injected between the first and second connectors to isolate the connectors from one another. The insulating material is typically epoxy or the like.

The isolating collar typically includes means for conveying electrical signals from outwith the collar to the second connector. Thus, any pipeline or tubing string coupled to the second connector is typically capable of carrying electrical signals.

The pipeline or tubing string is typically coated with an electrical isolating paint or the like to at least partially isolate the pipeline or tubing string.

The at least partially isolated pipeline or tubing string typically comprises a surface pipeline or tubing string. Alternatively, the at least partially isolated pipeline or tubing string comprises a subsea pipeline or tubing string, or a downhole pipeline or tubing string. It will be appreciated that the at least partially isolated pipeline or tubing string may further comprise any combination of surface, subsea or downhole pipelines or tubing strings.

The pipeline or tubing string typically includes a first isolating collar at or near a source of fluid flowing within the pipeline or tubing string. Optionally, the pipeline or tubing string includes a second isolating collar at or near a sink for the fluid in the pipeline or tubing string. The master unit is typically electrically coupled to the pipeline or tubing string via the first isolating collar. At least one slave unit is coupled to the pipeline or tubing string, preferably at one or more locations between said first and second isolating collars.

System components including the master and slave units may be earthed by being connected to a local earth. Alternatively, a system earth and/or

electrical return path may be provided by other tubulars such as a second pipeline or tubing string or by a downhole, surface or subsea casing or the like surrounding the pipeline or tubing string.

The slave unit typically comprises a mandrel, a slave module, and an electrical return path. The mandrel typically facilitates attachment of the slave unit to the pipeline or tubing string. The mandrel is typically clamped, or otherwise coupled, to the pipeline or tubing string. The mandrel typically facilitates transmission of the electrical power and data transmissions from the pipeline to the electronics of the slave unit.

The slave module typically houses the electronics of the slave unit. The electrical return path typically comprises a spring contact for engaging an earth point. The earth point may be a local earth, a further tubular such as a second pipeline, a subsea or surface casing or a casing of a downhole well.

The slave unit is typically coupled to the pipeline using a mandrel, pipeline clamp or other conventional means. The pipeline or tubing string typically includes a wellhead. A first isolating collar is typically located at or near the wellhead. The master unit is typically electrically coupled to the first isolating collar (and thus the isolated pipeline or tubing string) via a wellhead penetrator. Alternatively, the master unit may be electrically

coupled to the pipeline by directly attaching the output of the master unit to the pipeline using a pipeline clamp, or other conventional attachment means, for example a tubing clamp provided with a cable coupling.

Pulse-width modulation is typically used to facilitate data transmission from the master unit to the slave unit. The power transmission is typically modulated with the data transmission using pulse-width modulation.

Frequency-shift keying (FSK) is typically used to facilitate data transmission from the slave unit to the master unit. The FSK frequencies are typically superimposed on a carrier frequency. The carrier frequency is typically the same frequency as the power transmission frequency. The data transmission is typically synchronised to the "high" cycle of the power transmission. Alternatively, the data transmission may be synchronised to the "low" cycle of the power transmission, or optionally to both the low and high cycles, or to any range of cycles to circumvent the range of interference.

Where more than one slave unit is used, the data transmission from the master unit to the slave unit typically includes an address of the slave unit. This allows several slave units to receive commands from a single master unit.

The data transmissions preferably include data error detection and/or correction. The data error detection and/or correction typically comprise a Hamming code, or other suitable technique. Optionally where no DC or secondary power source is in the system the master and slave may optionally be DC coupled.

The master unit and/or the slave unit are preferably ac coupled to the transmission system using capacitors. Most preferably, the system employs separate and discrete capacitors for this purpose. This is known as capacitive coupling and allows any dc bias within the transmissions to be blocked, whilst passing any ac signals.

The master unit typically comprises a processor to control the operation of the master unit; a power waveform generator; and signal recovery and conditioning circuitry.

The processor typically applies pulse-width modulation to the power transmission when data transmission is required from the master unit to the slave unit. When not transmitting data, the processor typically defaults the power transmission to a 50% duty cycle.

The power waveform generator typically comprises an analogue driver, and a power drive electrically coupled to the analogue driver. The processor

typically applies the power transmission to the analogue driver. The analogue driver typically drives the power driver. The processor typically controls the voltage amplitude of the power transmission.

The analogue driver typically includes an isolating circuit that isolates the power driver from the processor. Typically, the analogue driver further includes low voltage logic drivers to high voltage driver stages, which in turn drive the power driver. This prevents any damage being caused to the processor.

The power driver typically comprises a field-effect transistor (FET) based push-pull driver. Alternatively, the power driver comprises a bi-polar transistor based push-pull driver, or the like. The power driver typically operates from a variable dc power supply. The master unit typically includes the variable dc power supply.

The signal recovery and conditioning circuitry typically allows data transmitted by the at least one slave unit to be extracted and recovered from the transmission system. The signal recovery circuit typically includes first and second data channels. The first data channel typically includes a high-speed switch; a filtering system; an automatic gain control (AGC) stage; a comparator stage; and a first counter.

The high-speed switch typically enables the data transmission to be directed to the first and/or second data channels when the power transmission is high. Alternatively, the high-speed switch directs the data transmission to the first and/or second data channels when the power transmission is low, or when the power transmission is both high and low.

The filtering system typically removes any noise and background signals from the recovered data. Typically, the filtering system comprises a pair of selective filters. The selective filters typically comprise broad bandpass filters. Alternatively, the selective filters may comprise tuned filters. This allows the filters to differentiate between the FSK frequencies.

The AGC stage typically maintains the signal within a set voltage amplitude range.

The comparator stage typically compares the voltage amplitudes of the FSK frequencies.

The slave unit typically comprises a processor to control the operation of the slave unit; rectifying and regulating circuitry in a first channel; recovery and conditioning circuitry in a second channel; and frequency generating and mixing means.

The rectifying and regulating circuitry typically comprises a half-bridge rectifier to rectify the received power transmission into a dc voltage; and at least one voltage regulator to regulate the dc voltage.

The recovery and conditioning circuitry typically comprises an amplifier and filtering system; and a timer circuit. The amplifier and filtering system typically amplifies or attenuates the signal, and filters the signal. This boosts the amplitude of the signal and removes any background noise or other interference.

The frequency mixing and generating means typically comprises a frequency-shift keying (FSK) generator; an FSK mixer; and a line driver.

The slave unit typically includes an analogue signal conditioning circuit, and at least one analogue-to-digital convertor. The analogue conditioning circuit allows the slave unit to receive and process signals from a plurality of sensors, such as pressure sensors, temperature sensors or the like.

The slave unit is typically capable of controlling loads.

Embodiments of the present invention shall now be described, by way of example only, with reference to the accompanying drawings, in which :-

Fig. 1 schematically illustrates an embodiment of a telemetry system coupled to an isolated pipeline;

Fig. 2 schematically illustrates an embodiment of a telemetry system similar to that of Fig. 1 with an additional slave unit;

Fig. 3 is a schematic block diagram of a telemetry system in accordance with one embodiment of the present invention;

Fig. 4 is a cross-sectional elevation of a first embodiment of an isolating collar for electrically isolating a pipeline;

Fig. 5 is a cross-sectional elevation of a second embodiment of an isolating collar for electrically isolating a pipeline, including an electrical connector;

Fig. 6a shows an exemplary power waveform for transmitting power from a master unit at the surface to a slave unit downhole;

Fig. 6b shows an exemplary signal transmit waveform for transmitting data from a slave unit to a master unit using frequency-shift keying (FSK);

Fig. 7a shows the power waveform of Fig. 2a modulated using pulse-width modulation for transmitting both power and data from a master unit at the surface to a slave unit downhole;

Fig. 7b shows how data is encoded in the modulated waveform of Fig. 3a;

Fig. 8a shows an exemplary power waveform transmitted on the isolated pipeline to which the telemetry system of Fig. 1 is attached;

Fig. 8b shows an exemplary power waveform for transmitting power from a master unit at the surface to a slave unit downhole;

Fig. 8c shows an exemplary signal transmit waveform for transmitting data from a slave unit to a master unit using frequency-shift keying (FSK);

Fig. 8d shows an enlarged portion of the waveform of Fig. 8c;

Fig. 9 is a schematic illustration of an oilwell that includes an isolated production tubing;

Figs 10a and 10b illustrate two examples of a wellhead penetrator;

Fig. 11 is a schematic illustration of a portion of the oilwell of Fig. 9 showing connection of an electrical signal to a pipeline or tubing string;

Fig. 12 is a cross-sectional elevation illustrating an embodiment of a slave unit of the telemetry system of Fig. 2 attached to an isolated pipeline or tubing string;

Figs 13a and 13b schematically illustrate a subsea pipeline installation with dual and single pipelines, respectively, with the telemetry system of Fig. 2 attached thereto;

Fig. 14 is a cross-sectional elevation illustrating a method of attaching a slave unit to a subsea pipeline;

Figs 15a and 15b schematically illustrate a surface pipeline installation with dual and single pipelines, respectively, with the telemetry system of Fig. 2 attached thereto;

Fig. 16 schematically illustrates a method of attaching a slave unit to a surface pipeline; and

Fig. 17 schematically illustrates an oilwell that has a subsea or surface pipeline attached thereto.

Referring to the drawings, Fig. 1 shows an illustrative embodiment of an exemplary embodiment of a telemetry system coupled to an isolated pipeline or the like according to the present invention. As shown more clearly in Fig. 3, the telemetry system comprises a master unit 10 and a slave or node unit 50. The master and slave units 10, 50 communicate with each other via a transmission system 12, i.e. a pipeline or well tubing string 100 (Fig. 1), that is at least partially isolated from earth, e.g. by means of at least one isolating collar 200 (Figs 4 and 5). In the embodiment shown in Fig. 1, a first isolating collar 200a is located at a first end of the pipeline 100. Optionally, a second isolating collar 200b may be positioned at a distal end of the pipeline 100 at the end of a transmission zone, the transmission zone being defined between the first and second isolating collars 200a, 200b.

The master unit 10 typically includes a power supply and controller unit that generates an electrical power supply, and also transmits data to and receives data from the remote slave unit 50. The slave unit 50 is powered by the master unit 10 as will be described hereinafter, and can carry out control and monitoring functions from where it is coupled to the isolated pipeline 100. The master and slave units 10, 50 require the electrical circuit to be completed by connection to an electrical ground or earth point, as schematically shown in Fig. 1.

In this way, sensors, instrumentation systems or load actuators coupled to the slave unit 50 can be monitored and the load actuators can be controlled from the master unit 10 using only the pipeline 100 for transmission of power and data transmissions. Further the slave unit 50 can be coupled at any point in the isolated portion of the pipeline 100 (i.e. the transmission zone defined between isolating collars 200a, 200b).

As shown in Fig. 2, the system can support more than one slave unit (i.e. slave units 50a, 50b) coupled to the isolated portion of the pipeline 100. The system can support multiple slave units 50a, 50b etc, with each slave unit 50a, 50b etc, being coupled to the pipeline 100 at any point in the isolated portion.

The system may be configured to transmit either solely the power supply transmissions from the master

unit 10 to the slave unit 50, or to include data transmissions in addition to transmitting power. The data transmission is typically synchronised to the power supply transmission and/or with a secondary and larger power source running in parallel with the power supply and data transmissions from the master unit 10 to the slave units 50. This secondary power source can either be used for pipeline heating and/or powering large power actuators and motors attached to the isolated portion of the pipeline 100.

The master unit 10 is typically located at the surface, and the slave unit 50 is typically located remote from the master unit 10, for example in a borehole, oilwell, subsea installation or the like. The location of the master unit 10 is dependent upon the particular application, and the relative positions of the master unit 10 and the slave unit(s) 50 described herein are by way of example only.

It should be noted that a number of slave units 50 may be coupled to the transmission system 12 (i.e. the pipeline 100), and the operation of each slave unit 50 controlled by the master unit 10 at the surface. It should also be noted that the system may use more than one master unit 10 if control of the slave unit(s) 50 is required from more than one point in the system.

The master and slave units 10, 50 are advantageously coupled to the isolated pipeline 100 using capacitive

coupling. Discrete capacitors 14, 52 (Fig. 3) are coupling or blocking capacitors that couple a signal from a power source (discussed later) to the isolated pipeline 100. Capacitors 14, 52 block any direct current (dc) bias that may be applied to the signal, but do not affect any alternating current (ac) signal that is simultaneously transmitted. When considering dc, the capacitors 14, 52 act as open circuits as, at zero frequency (dc), the reactance of a capacitor is infinite.

Referring now to Fig. 3, the master unit 10 includes a power input stage 16 that provides power for the telemetry system, and may be either an ac or dc power source. The power input stage 16 is electrically coupled to at least one (and preferably a plurality of) dc voltage regulators 18. Voltage regulators 18 provide local power supplies (dc) for the circuitry in the master unit 10. Generally, different components within the master and slave units 10, 50 operate using a plurality of different voltages, depending upon the various specifications of these components.

The master unit 10 includes a processor 20 that, among other functions, controls the operation of the telemetry system. One output of the processor 20 is electrically coupled to an analogue driver stage 22, the driver stage 22 being electrically coupled to a high voltage ac power driver 24. The output of the

power driver 24 is electrically coupled (via the coupling capacitor 14) to the isolated pipeline 100.

The power driver 24 may be a field-effect transistor (FET) or a bi-polar transistor based push-pull drive stage, that typically operates using a variable but relatively large dc voltage power supply. The dc power supply is typically rated from 20 to 500 volts, although voltages outwith this range may also be used. The particular voltage used is dependent upon the loading conditions and losses in the isolated pipeline 100, and can be varied accordingly.

The power driver 24 is preferably electrically isolated from the processor 20 to prevent damage to the processor 20. Thus, the analogue driver stage 22 includes isolating circuits and low voltage logic drivers to a high voltage drive stage, which in turn drives the gates of the FET or bi-polar transistor power driver 24.

The master unit 10 further includes a signal recovery circuit 26 that retrieves data transmitted (via the isolated pipeline 100 as will be described) by the slave unit 50. The processor 20 controls operation of the signal recovery circuit 26. The recovered data from the signal recovery circuit 26 is processed by a filtering system 28 that further extracts the received information from any noise or other background interference mixed with the recovered data from the slave unit 50.

The output from the filtering system 28 is fed into a signal conditioning unit that includes an automatic gain control (AGC) stage 30, and a comparator stage 32. The output of the comparator stage 32 is fed into a first counter 34. The first counter 34 is electrically coupled to the processor 20, so that the processor 20 can read the value in the first counter 34.

In certain embodiments of the present invention, the raw signal from the slave unit 50 is additionally fed into a second data channel that includes a signal recovery circuit 36 to extract data from the power transmission on the isolated pipeline 100. The output from the second signal recovery circuit 36 is fed into a timer circuit 38 that performs pulse-width measurements on the data extracted from the power transmission. The output of the timer circuit 38 is fed into a second counter 40, the value in the counter being read by the processor 20.

A remote station (not shown) typically controls operation of the master unit 10, and is electrically coupled to the master unit 10 via a serial data link 46, such as an RS232/485 serial data port. The remote station may be, for example, a personal computer located remotely from the master unit 10.

The slave unit 50 includes a half-wave rectifier and heat dissipation unit 54. This unit 54 extracts

power transmitted via the isolated pipeline 100 to the slave unit 50 as will be described. As with the master unit 10, the slave unit 50 has a matched pair of voltage regulators 56 and a plurality of low voltage dc regulators 58 to provide local power supplies for the circuitry in the slave unit 50.

The slave unit 50 is provided with a processor 60 to control the operation thereof. The processor 60 is electrically coupled to a line driver 62 that transmits data onto the isolated pipeline 100.

In certain embodiments, the slave unit 50 transmits data to the master unit 50 (via the isolated pipeline 100) using frequency-shift keying (FSK), as will be described. A frequency generator 64 is used to generate the two required frequencies F_1, F_2. The frequencies F_1, F_2 are then mixed by a frequency mixer 66 to combine data from the processor 60 with carrier frequency F_c and the modulating frequencies F_1, F_2.

The slave unit 50 further includes a signal recovery circuit 68 to extract data from the isolated pipeline 100 generated by the master unit 10. A timer circuit 70 is used to perform pulse-width measurements on the data extracted by the signal recovery circuit 68.

The slave unit 50 is provided with an analogue signal conditioning circuit 74, and a plurality of analogue-to-digital (A/D) convertors 76. The analogue conditioning circuit 74 and the A/D convertors 76

allow a plurality of different types of instrumentation and/or sensors (not shown) to be coupled to the system. Thus, the slave unit 50 monitors these instruments and sensors and transmits data procured by them to the master unit 10 for collection and analysis.

The slave unit 50 can accept a wide range of sensors, and any electronic sensor that can be conditioned and measured using a processor can be used with the system. Typical sensor inputs to the analogue signal conditioning circuit 74 comprise either analogue sensors with voltage outputs, or those with frequency outputs. Typical examples of analogue sensors that may be used to collect information include pressure sensors, temperature sensors, accelerometers and fluid depth sensors (resistive or capacitive). Typical examples of frequency or pulse output sensors, include shaft speed indicators, high accuracy pressure and temperature sensors and flow meters. These are exemplary only, and the range of applications will be apparent to those skilled in the art.

The analogue sensors coupled to the system can be powered from the low-level regulators 58 in the slave unit 50. The voltage or current outputs from the sensors would be amplified or filtered in the analogue signal conditioning circuit 74 if required, and the conditioned outputs fed into the multiplexed

A/D convertor 76, the outputs then being fed to the processor 60 for transmission in digital format.

The data system architecture within the system typically operates using 16 or 24 bit data words for transmission, and read values can be transmitted to the master unit 10 as A/D counts in either 16 or 24 bit words, depending upon the required accuracy and resolution of the measurements.

Where pulse or frequency signals are output from the sensors, a reciprocal counter could be used to measure the frequency locally in the analogue signal conditioning unit 74. In this embodiment, the processor 60 typically forms part of the reciprocal counter to minimise or reduce the electronics required in the slave unit 50.

In addition to sensor measuring capabilities, the system could be utilised to control loads. As the system in certain embodiments can facilitate two-way communication, any electronic control that can be implemented with the local processor 60 can be implemented using the telemetry system. For example, the slave unit 50 may be used to control solenoids to operate and control actuators, hydraulic valve mechanisms, motors that open valves, or other similar functions.

Operation of the telemetry system shall now be described. The processor 20 in the master unit 10

applies a power waveform to the driver 22 under command from the remote station. The driver 22 drives the power driver 24 that applies a square-wave power waveform (Fig. 6a), the power waveform being transmitted to the isolated pipeline 100 through the coupling capacitor 14.

Fig. 6a shows an exemplary power signal waveform that is transmitted from the master unit 10 to the slave unit 50 via the isolated pipeline 100. The frequency of the waveform may be any suitable frequency; a typical frequency range may be from 10 millihertz (mHz) to 6 kilohertz (kHz) although frequencies outwith this range may be used. Where there is even a moderate bandwidth on the isolated pipeline 100, the frequencies used to transmit power from the master unit 10 to the slave unit 50 will be from 100 Hz to 100 kHz.

The amplitude of the waveform is variable and is dependent upon the loading conditions and losses of the isolated pipeline 100. The processor 20 using a regulator (one of the plurality of regulators 18) controls the voltage amplitude of the square-wave power waveform (Fig. 6a). By controlling the amplitude of the power waveform using a processor 20, the amplitude may be adjusted either manually or automatically to set and keep the amplitude constant in varying operating conditions.

The slave unit 50 receives an attenuated power input from the isolated pipeline 100 through the coupling capacitor 52. Any background noise or other interference will be added to the power signal during transmission from the master unit 10 to the slave unit 50, thus resulting in a degraded signal being detected at the slave unit 50. The power is rectified through the half-bridge rectifier 54 and is then regulated in the regulating units 56, 58 to provide the local power supplies for the various circuitry within the slave unit 50.

Fig. 6b illustrates how data may be transmitted from the slave unit 50 to the master unit 10. Data is transmitted using frequency-shift keying (FSK) in a continuous stream during data transmission. Two FSK frequencies F_1, F_2 are superimposed on a carrier frequency F_c. In the example shown in Fig. 6b, the carrier frequency F_c is the same frequency as the power waveform of Fig. 6a, and the data transmission is synchronised to the "high" cycle of the power waveform shown in Fig. 6a. It should be noted that the data may be synchronised to the "low" cycle, or to both the high and low cycles. This synchronisation allows the master unit 10 to correctly detect the data transmission from the slave unit 50.

The frequencies used to transmit data from the slave unit 50 are typically several hundred kilohertz (kHz). For example, the transmit frequencies F_1, F_2

from the slave unit 50 to the master unit 10 may be 300 kHz for a logic one and 100 kHz for a logic zero. Thus, if a logic one is to be transmitted, then the higher of the two FSK frequencies (i.e. F_1) will be transmitted for the duration of the high cycle of the power waveform, and if a logic zero is to be transmitted, the lower of the two FSK frequencies (i.e. F_2) is transmitted for the duration of the high cycle of the power waveform.

The two FSK frequencies F_1, F_2 are preferably not multiples of one another to minimise the occurrence of false detections. The two frequencies F_1, F_2 are typically also at least a factor of two different. Although this increases the amount of bandwidth required on the isolated pipeline 100, it allows for the recovery of highly attenuated signals. Where there is significant inductance on the isolated pipeline 100, much lower frequencies may be used. This reduces the speed of the system, but does not affect the ability of the system to transmit and receive data. Low carrier frequencies may be used (in the order of a few hertz) with very high frequency data carriers to increase data recovery in noisy environments, such as that downhole. Where low frequencies are required, the system may also be used with fractions of a hertz for the carrier, and a logic zero frequency of 100 Hz and a logic one frequency of 350 Hz, for example.

Power across the slave unit 50 can be adjusted to provide the power supplies necessary for the type of electronics being operated. For example, for any instrument systems being operated downhole, ±15 volts is normally required. Thus, the ac power across the (downhole) slave unit 50 will be in the order of ±30 volts to maintain the power supplies at a stable level (due to losses etc).

The data recovery circuit 26 in the master unit 10 operates as follows. The low-level signal transmitted by the slave unit 50 is sensed using a sense resistor 42. The signal from the slave unit 50 develops a voltage across the sense resistor 42 as the output of the push-pull power driver 24 is effectively an ac ground.

The value of sense resistor 42 is typically twenty times the resistive value of the isolated pipeline 100. For example, if the resistive value of the isolated pipeline 100 is 10 ohms (Ω) from a master injection point 44 (Fig. 3) to the slave unit 50, then the sense resistor 42 would have a value of 200Ω. The value of this sense resistor 42 can be chosen to match the particular isolated pipeline 100.

The raw signal from the sense resistor 42 is then processed by the first data channel that includes the first signal recovery circuit 26, and is fed through an analogue high speed switch (not shown, but forms part of the signal recovery circuit 26). The

processor 20 or a local zero-crossing detection circuit or the like, enables data to be directed to the first data channel only when the power waveform is high, thus facilitating the synchronisation. The data channel then only receives and processes valid segments of the recovered data. It should be noted that the triggering mechanism for directing data into the data channel may be configured to allow transmission when the power waveform is low, or both when it is high and low.

The sampled data is then fed through the filtering system 28 that, in simple applications, typically comprises a single broad bandpass filter. In noisy applications, it is preferable to use a pair of selective filters designed for each transmit frequency F_1, F_2. It may also be necessary in exceptionally noisy environments to use tuned filters.

The signal recovered from the filtering system 28 is then fed through an automatic gain control (AGC) stage 30. The AGC stage 30 maintains the amplitude of the recovered signal within a set amplitude range. The frequency response of the AGC stage 30 is typically sufficient to allow the AGC amplifier to correct for changes in amplitude over one cycle of either the transmission medium power frequency or the telemetry system power frequency, whichever is the higher frequency. The AGC stage 30 performs two functions. It compensates for the difference in

amplitude from the high carrier to the low carrier frequency received (i.e. the difference in amplitudes between F_1 and F_2). In addition, there may also be variations in the amplitude of the received signal over the time period of the high cycle of the power waveform frequency (i.e. variations in amplitude of the signal during a single bit transmission). The AGC stage 30 must be able to react quickly enough to compensate for these changes without becoming unstable. Thus, the frequency response of the AGC stage 30 is related to the frequency of the power waveform, and the bandwidth of the AGC stage 30 is typically ten times greater than the power waveform frequency (i.e. ten times greater than the baud rate).

The recovered signal is then fed into the comparator stage 32, the output of which is fed into the first counter 34. The comparator stage 32 compares the signal level of each of the two FSK frequencies F_1, F_2 to establish which is present. The output of the comparator stage 32 is a signal that contains either one of the two FSK frequencies F_1, F_2. The first counter 34 then counts the number of pulses in the signal from the comparator stage 32, and the processor 20 reads the value in the first counter 34 to determine which of the two FSK logic frequencies F_1, F_2 are present (i.e. either the frequency relating to a logic one or zero).

The slave unit 50 transmits in a continuous stream of digital data (i.e. ones and zeros), with each high cycle of the power waveform containing one of the two FSK frequencies F_1, F_2 representing either a logic one or zero. The process is thus continued for each high cycle of the power waveform to determine whether a one or a zero was transmitted in each high cycle. Once the processor 20 has determined whether a one or a zero was sent in each high cycle, the processor 20 may reconstruct the transmitted digital data from the slave unit 50.

The slave unit 50 may also transmit bursts of transmitted data in a poll response mode. In the poll response mode, there are three states for transmission from the slave unit 10 to the master unit 50: a logic one, a logic zero and a "none" state. Thus, when not requested to transmit data the slave unit 50 ceases transmission. This poll response mode is typically used where multiple slave units 50 are operating on the same transmission system.

Figs 7a and 7b illustrate a power and data transmission waveform respectively, for the transmission of data from the master unit 10 at the surface to the slave unit 50. Data is transmitted from the master unit 10 to the slave unit 50 using pulse-width modulation. Use of this technique allows the signal recovery circuitry in the slave unit 50 located downhole to be less complex than that in the

master unit 10, thus reducing the size, cost and power consumption of the slave unit 50.

Fig. 7a illustrates the power waveform transmitted when data is being transmitted from the master unit 10 to the slave unit 50. In order to transmit digital data, the width of the pulses in the waveform are modified to represent either a digital zero or one. This technique is termed pulse-width modulation. Fig. 7b illustrates the difference in pulse-widths between a logic one and zero as an example. There are typically three different pulse-widths (frequencies) used, each relating to either a logic one, a logic zero or an idle state. The idle state is typically used to aid specific command recovery in the slave units 50. For example, where there is more than one slave unit 50 coupled to the system, each unit 50 remains in the idle state and polls the data transmissions from the master unit 10 until it receives a command intended for that particular unit 50 identified by the command string.

When data is transmitted from the master unit 10 to the slave unit 50 using pulse-width modulation, the signal received at the slave unit 50 is fed through a second ac coupling capacitor 72 into a signal recovery circuit 70, that includes an amplifier and filtering system. The signal is amplified or attenuated, depending upon the application.

The relative frequency of the main transmission system power, and the frequency of the telemetry power carrier Fc determine the value of the coupling capacitor 72. The value is chosen so that the capacitive decoupling acts as a high pass filter to remove substantially all of the transmission system power waveform whilst recovering as much of the telemetry system power waveform as possible.

The requirement to either attenuate or amplify the signal after decoupling depends upon the attenuation of the high pass filter described above. As the signal is superimposed on the power waveform, it will have a substantial peak-to-peak voltage at the slave unit 50 connection. If this large voltage signal is decoupled without any substantial losses, the recovered signal fed to the first stage amplifiers in the signal recovery circuit 68 will exceed the supply rails and will thus require to be attenuated.

However, if the signal is decoupled with a substantial amount of low frequency rejection (i.e. through a high pass filter), then the signal fed to the first stage amplifier will be relatively small and will thus require to be amplified. The requirement to amplify or attenuate the signal is dependent upon the relative frequency of the power waveform to the transmission medium frequency.

The recovered and filtered signal is then fed into a processor-controlled timer circuit 70. The timer

circuit 70 may be replaced by a re-triggered monostable. The timer circuit 70 allows pulse-width measurements to be taken to determine whether a one or a zero was sent. The processor 60 can then reconstruct the data transmission from the master unit 10 to the slave unit 50 by analysing and recording each pulse-width in turn to determine the sequence of ones and zeros in the data transmission.

Data sent by the master unit 10 to the slave unit 50, or vice versa, is typically encrypted by use of a Hamming Code, or other suitable data error detection and correction encoding scheme. The data from the master unit 10 may also include the address of the slave unit 50 in the command string so that several slave units 50 may receive different and individual commands from a single master unit 10.

Where the isolated pipeline 100 is particularly noisy or there is a large degree of background interference, it is often not possible to determine from the method described above whether a logic one or zero was transmitted. To overcome this, the recovered data is not measured as one of two frequencies in windows delineated from the power waveform, but each data detection window that is seen by the processor 20 at the surface is sub-divided into several sub-windows. Figs. 8a to 8d illustrate this technique.

To operate correctly using this sub-dividing technique, it is preferable to use a second data channel within the master unit 10 that includes the second signal recovery circuit 36, the timer circuit 38 and the second counter 40.

The telemetry system may be coupled to any isolated pipeline 100 or a tubing string. For example, it may be coupled to an existing pipeline that is used to recover hydrocarbons from a borehole, subsea well or the like. Fig. 8a shows a typical power waveform that may be present on the isolated pipeline 100 and may be, for example, a power waveform that is driving a downhole motor. The second data channel in the master unit 10 is used to determine the fundamental operating frequency of the power waveform for the downhole motor. The processor 20 within the master unit 10 uses the second counter 40 to establish the frequency at which the power waveform on the isolated pipeline 100 is operating, using a similar technique as described above to determine whether a zero or a one was sent. The processor 20 then synchronises the transmitted power for the slave unit 50 (waveform shown in Fig. 8b) to the same frequency, or a multiple thereof, as the power frequency of the isolated pipeline 100. Thus, the power and data transmissions are synchronised to the frequency of the power on the isolated pipeline 100 over which they are transmitted (i.e. they are synchronised with the source of the noise which can cause a loss of signal) thus reducing the effect of the noise.

Fig. 8b shows an exemplary power waveform for transmission of power and/or data from the master unit 10 to the slave unit 50. The waveform shown in Fig. 8b is similar to that shown in Fig. 6a and may operate over the same frequency range (i.e. in the order of a few mHz to several kHz).

Fig. 9c illustrates the data transmission from the slave unit 10 downhole to the master unit 50 at the surface. The waveform is similar to that shown in Fig. 6b wherein the data transmission is superimposed upon and synchronised to the high cycle of the power waveform. Although the example shows data being superimposed on and synchronised to the high cycle, it should be noted that data could also be superimposed on and synchronised to the low cycle or both.

Frequency-shift keying (FSK) is used to transmit data from the slave unit 50 to the master unit 10. In the example shown in Fig. 8c, F_1 that represents a logic one is 200 kHz and F2 that represents a logic zero is 90 kHz. As with the previous example, the two FSK frequencies F_1, F_2 are preferably not multiples of one another to minimise the occurrence of false detections. The two frequencies F_1, F_2 are typically also at least a factor of two different. Although this increases the amount of bandwidth required on the isolated pipeline 100, the system allows for the recovery of highly attenuated signals. Where there

is significant inductance on the isolated pipeline 100, much lower frequencies may be used. This reduces the speed of the system, but does not affect the ability of the system to transmit and receive data. Low carrier frequencies may be used (in the order of a few hertz) with very high frequency data carriers to increase data recovery in noisy environments, such as those downhole. Where low frequencies are required, the system may also be used with fractions of a hertz for the carrier, and a logic zero frequency of 100 Hz and a logic one frequency of 350 Hz, for example.

The frequency used to transmit data to and from the slave unit 50 is typically several hundred kilohertz (kHz). For example, the transmit frequencies F_1, F_2 from the slave unit 50 to the master 10 may be 200 kHz for a one and 90 kHz for a zero. Thus, if a logic one is to be transmitted, then the higher of the two FSK frequencies F_1 (i.e. 200 kHz) will be transmitted for the duration of the high cycle of the power waveform, and if a logic zero is to be transmitted, the lower of the two FSK frequencies F_2 (i.e. 90 kHz) is transmitted for the duration of the high cycle of the power waveform.

However, where the isolated pipeline 100 is particularly noisy, for example where the transmission system 12 is also used to drive a downhole motor, it may not be possible to determine whether a logic one or zero was sent from the basic

counter discrimination technique. A further technique is used to aid in discriminating between a logic one and zero that sub-divides each of the data windows in the data transmission waveform into a series of sub-windows. An example of a sub-window is shown in Fig. 8d, which is an enlarged view of one of the data windows from the waveform in Fig. 8c. The data window is sub-divided into a number of sub-windows, such as ten shown in Fig. 8d. Each of the ten sub-windows is then studied and measurements taken to determine which of the two FSK frequencies (i.e. F_1 or F_2) is present within that sub-window.

Every high period (the receive window) of the slave unit power waveform (Fig. 8c) is segmented in the processor code into smaller time slots (typically ten per receive window). When the system is first initiated, or on command from the master unit 10, the slave unit 50 transmits a specified pattern of ones and zeros to calibrate the transmission data windows. The master unit 10 receives and processes this pattern and determines from the pattern received the reliability of the recovered data. The reliability of the recovered data indicates which of the sub-windows in the received window has reliably transmitted a one or a zero. The sub-windows in which a one or a zero cannot be reliably recovered are mapped as being "not usable" in the memory of the processor 20 and are thus not used for data recovery. In this way, the reliability of the system is increased, as the test transmission allows the system

to assess which sub-windows are being affected by noise and other interference, these sub-windows then being ignored for future transmissions. This technique allows for enhanced reliability and also the ability to allow the system to be calibrated to particular environments.

Thus, this technique provides a method of data transmission and recovery that uses sub-divided and synchronised data recovery windows to enhance the noise immunity of the system, and also the use of a calibrating pattern to allow the master unit 10 to determine the reliable portions of the recovered data transmitted by the slave unit 10.

Referring to Fig. 4, isolating collar 200 is used to provide electrical isolation whilst maintaining pressure sealing in the pipeline 100. Isolating collar 200 is described in US Patent Nos 4,861,074 and 4,716,960 assigned to Production Technologies Inc, the entire disclosure of these patents being incorporated herein by reference thereto. The function of isolating collar 200 is conventionally to electrically isolate at least a portion of the pipeline, wherein electrical power is applied to the pipeline or tubing string to facilitate heating of the pipeline or tubing string. Heating of the pipeline or tubing string is to prevent the formation of solids, particularly for use with pipelines or tubing strings containing paraffin.

Isolating collar 200 is provided with threads 204 at an upper end of an inner connector 202. Threads 204 facilitate connection of the isolating collar 200 to a tubing string or the like thereabove. Inner connector 202 is substantially tubular and is typically of a steel construction with material to suit the pipeline or tubing string to which it is attached.

Inner connector 202 is provided with a continuous screw thread 206 on an exterior surface for engagement with an inner insulating seal sleeve 208. Inner sleeve 208 is provided with a thread 210 that allows it to be threadedly coupled to the thread 206 of the inner connector 202, and a thread 212 provided on the interior of an outer connector 214. Inner connector 202 is typically provided with sealing means, such as O-rings 218, at a lower end thereof to seal against sleeve 208.

Outer connector 214 is typically formed of electrically conducting material such as steel, and is concentrically attached to the inner connector 202 to be supported thereby. Outer connector 214 is provided with an internal thread 216 at a distal end thereof to facilitate connection of the isolating collar 200 into a pipeline or tubing string attached therebelow. The distal end of outer connector 214 is also provided with sealing means, for example O-rings 220, on the inner bore thereof for sealing with the sleeve 208.

An insulating material 222 is typically injected into an annulus between the inner and outer connectors 202, 214 via a port 226. The insulating material 222 provides for electrical insulation between the inner and outer connectors 202, 214, and can additionally provide mechanical strength to support the weight of the string below the collar 200. The insulating material may be, for example, an epoxy such as aromatic amine.

The insulating material 222 typically includes sleeve 208 that is typically formed of a plastic material. Sleeve 208 bridges the space between the lower end of the inner connector 202 and the seal means 220 and prevents electrical contact between the inner and outer connectors 202, 214 through water being contained within the fluids flowing through the collar 200.

Sleeve 208 and the first and second seals 218, 220 insulate between the inner and outer connectors 202, 214 and additionally prevent fluids from reaching the insulating material 222 from the interior of the isolating collar 200. The insulating material 222 is preferably protected from contact with well fluids that may cause a short circuit within the isolating collar 200.

In certain embodiments of the isolating collar 200, a nonsolid, noncompressible material is injected into

cavities in the lower end of the isolating collar 200. This material is confined under pressure so that sleeve 208 is supported against internal pressure. Thus, as pressure within the bore of the isolating collar 200 increases, the pressure on the nonsolid material increases and no substantial pressure differential is created. The material is preferably silicone. Before the nonsolid material is injected, the area that it fills is typically evacuated.

Isolating collar 200 is based on an oilfield thread for coupling but can be adapted to other pipe coupling threads and indeed flange couplings without compromising or altering the core design of the collar. Thus, those skilled in the art will appreciate that isolating collar 200 can be coupled to the pipeline or tubing string in any conventional manner, depending upon the particular application and/or the structure of the pipeline or tubing string.

Isolating collar 200 includes a ring 228 that allows external electrical power and transmissions to be coupled to the outer connector 214. Ring 228 is provided with internal threads 230 that engage external threads 232 on an upper end of the outer connector 214. A blind conduit 234 is provided on the ring 228 to allow for connection of electrical signals using any conventional means. Thus, electrical signals, such as power and/or

communications, may be transmitted via the outer connector 214 to any receiver that is electrically coupled to the pipeline or tubing string suspended below the isolating collar 200.

Fig. 5 shows an alternative embodiment of an isolating collar 300. Collar 300 is substantially the same as collar 200. Isolating collar 300 is described in US Patent Nos 4,861,074 and 4,716,960 assigned to Production Technologies Inc, the entire disclosure of these patents being incorporated herein by reference thereto.

Isolating collar 300 includes an upper connector 302 and a lower connector 304. The upper and lower connectors 302, 304 are threadedly coupled using threads 306 on the upper connector 302 and threads 308 on the lower connector 304. It should be noted that the upper and lower connectors 302, 304 may be coupled in any conventional manner.

The cavity between the threads 306, 308 is preferably filled with an insulating material 310 as in the previous embodiment, the material 310 typically being epoxy. The insulating material 310 typically provides for electrical insulation between the two connectors 302, 304, and the interlocking threads 306, 308 give mechanical support to allow a tubing string to be suspended from the lower connector 304.

The lower connector 304 is provided with a threaded bore 312 for receiving an electrical conduit 314.

The upper and lower connectors 302, 304 are provided with a central bore 302b, 304b respectively, to allow the passage of fluids through the collar 300, and also threads 302t, 304t respectively, to allow the collar 300 to be coupled into a tubing string or pipeline.

The upper connector 302 is provided with a counterbore 316 that receives the electrical conduit 314. The counterbore 316 is typically filled with epoxy insulating material when the electrical conduit 314 is in place.

Electrical conduit 314 typically comprises a metal rod having a lower threaded end 314l for threadedly engaging threaded bore 312 in the lower connector 304 to facilitate electrical connection. The conduit 314 has an enlarged diameter portion 314e to reduce the electrical resistance of the conduit 314 in the area of the enlarged portion 314e, so that the insulating material in this area is not overheated when high power signals are transmitted.

The electrical conduit 314 is provided with an electrical connector 318 at its upper end, the connector 318 being attached by any suitable means, such as a screw thread. The connector 318 is provided with a blind internal bore 320 to which

electrical connection may be made, for example by soldering. The connector 318 is typically electrically insulated by using a rubber boot, for example, positioned over the connector 318.

Thus, both isolating collars 200, 300 facilitate electrical isolation of the pipeline above the collars 200, 300 but allow transmission of electrical signals on the pipeline suspended below the collars 200, 300.

In addition to the use of the isolating collar 200, 300 the pipeline system 100 (Fig. 1) is preferably isolated form electrical ground between the collars 200a, 200b to maintain the isolation. This requires the pipeline to have a degree of insulation or be spaced off any grounded objects, by insulating mounts or protectors, as will be described hereinafter.

It will be appreciated that the pipeline 100 is required to be isolated to some extent from ground.

Referring now to Fig. 9, there is shown an oilwell, generally designated 400, with tubular casing 412 and a pipe based production tubing. The oilwell generally includes a well head 402 that may be of any conventional type, that has a tubing string suspended therebelow. The tubing string typically comprises a plurality of tubulars 404 that are coupled together in a known manner (such as by threaded couplings). A number of isolating collars 200a, 200b, 200c are

coupled into the tubular string at specified locations, to electrically isolate the tubular string. The isolating collars 200 may comprise the isolating collars 300.

The master unit 10 can be either directly or capacitively coupled to the single wire connection to the downhole system, via the isolating collar 200a. Power and data transmissions to and from the master unit 10 are driven between the single live contact through a wellhead penetrator 406 provided in the wellhead 402. The wellhead penetrator 406 would be the type of penetrator used for electrical submersible pump (ESP) installations or permanent gauge installations. Fig. 10 shows a typical penetrator 406, although any proprietary well head penetration device with suitable pressure and electrical rating may be used.

Referring now to Figs 10a and 10b, the function of a wellhead penetrator 406 is to allow electrical cables to be fed through an oil field wellhead 402. The wellhead 402 forms a pressure cap on the well and so any electrical penetration has to maintain the pressure seal of the wellhead 402.

Fig 10a illustrates an API flange unit, and Fig. 10b illustrates an NPT mounted unit, but both units perform the same function and are substantially the same. The penetrators 406 include a primary pressure seal 450 that typically comprises a metal-to-metal

seal. Seal 450 couples the body of the penetrator 406 to the wellhead (schematically shown in Figs 10a and 10b as 452) itself. A seal 454 seals against a cable running through the wellhead 452 itself, seal 454 typically being a metal-to-metal seal.

A glass-to-metal electrical penetrator allows electrical inner conductors to pass through a pressure-tight barrier 456.

The penetrator 406 includes a connector 458 to facilitate coupling of an external cable onto the wellhead penetrator 406. Connector 458 may comprise a gland or any other type of cable exit.

The penetrator 406 may be mounted to the wellhead 452 using any conventional means, such as bolts 460 (Fig. 10a) or a screw thread 462 (Fig. 10b). The wellhead protector 406 typically includes a pressure-tight steel body 464 that houses and generally mounts the major components of the penetrator 406.

The single wire from the base of the penetrator 406 is fed on to the isolating tubing collar 200a mounted below the wellhead 402 and a tubing hanger 408 (Fig. 9). Electrical contact between the single wire of the wellhead penetrator 406 and the isolated portion of the tubing below the isolating collar 200a can be achieved by using either of the isolated collars 200, 300 described herein, or otherwise.

Alternatively, the single wire of the wellhead penetrator 406 can be coupled directly to any part of the isolated tubing string using a simple tubing based connection as shown in Fig. 11. Fig. 11 schematically illustrates the wellhead penetrator 406 and two methods of coupling the wire from the penetrator 406 to the isolated portion of tubing. The first method is described above, wherein the isolating collar 200a is used to transmit electrical signals from the wellhead penetrator 406 to the isolated portion of the tubing string.

Alternatively, the wire from the wellhead penetrator 406 may be coupled to the isolated pipeline using a cable coupling (not shown) that is coupled to a tubing clamp 410.

Referring again to Fig. 9, the tubing string is prevented from touching casing 412 of the oilwell 400 by insulated protectors 414. The insulated protectors 414 can be mounted at either couplings 416 between successive tubulars 404 or at a mid point 418 in the length of a tubular 404. The insulated protectors 414 are typically of a rubber or plastic construction and are commonly used in the oil and gas industry. They are generally two types of protectors 414, either protecting across the tubing joint (cross coupling protectors) such as at coupling 416 or clamping at any point in the pipe (mid joint protectors) such as at mid point 418.

The slave units 50 are typically mounted to the production tubing 404. In this example, two slave units 50a, 50b are shown. Fig. 9a shows an enlarged view of a section of the tubing of Fig. 9 illustrating how the slave units 50a, 50b are coupled to the tubing string. Slave units 50a have a carrier or mandrel 420 that attaches the slave unit 50a to the tubing 404, a slave module 422 that contains the electronic circuitry described above, and an electrical return path that typically comprises the casing 424 of the slave unit 50a. Casing 424 typically comprises a spring contact.

The slave unit 50a is further illustrated in Fig. 12. The slave unit 50a is electrically connected to the tubing 404 by clamping the electronic module 422 containing the circuitry onto the tubing based mandrel 420. Mandrel 420 may be machined from solid steel, fabricated or a combination of solid machining and bolted clamps. The general structure of the mandrel 420 is of steel to suit the rest of the tubing string. The electronics of the slave unit 50a are isolated from a protective pressure housing 426, housing 426 being conventionally grounded, but being live in this particular embodiment. The electronic module 422 mounted to the mandrel 420 has insulated end pieces 428 that the spring contact 424 is mounted to. This electrically isolates the spring loaded contacts 424 from both the mandrel 420 and the body of the electronic module 422. The slave unit pressure housing 426 typically supports the spring

contact 424 and also maintains pressure integrity during wiping action of the spring contact 424.

Thus, the electronics in the electronics module 422 is coupled between the live pipe or tubing 404 and the ground potential casing 412 (not shown in Fig. 12), thus drawing power from the live tubing 404.

The simplest return path connection is a spring-loaded wiper arm 424 (Fig. 12), that pushes against the casing 412 of the well 400. The electrical return contact can be a hydraulically operated latching arm (not shown) or alternatively, may comprise the grips of a hydraulically set packer (not shown).

Thus, the slave units 50 are electrically coupled to the master unit 10 using only the production tubing 404 and can monitor sensors and control actuators (not shown) as described above.

Furthermore, the telemetry system can be used in a multi-lateral well (several branches downhole from a single borehole) and slave units 50 can be installed in each of the multiple branches (not shown). Thus, the system may operate with multiple slave units 50 in various branches of the well, with all of the slave units 50 acting in parallel on the same system, and with no requirement for any splicing or joint in the system other than a union on the tubing system 404 that is inherent for the well to function.

Referring again to Fig. 9, the system is shown as having multiple slaves 50a, 50b, 50c coupled to the production tubing 404 at any convenient locations. The slave units 50a, 50b, 50c may be positioned to allow for the control, operation and interrogation of a plurality of different instruments, sensors or load actuators as required.

Where a slave unit 50 requires to be mounted below a packer or valve 430 (which cannot be isolated electrically from the casing 404) an isolating tubing collar 200b will be mounted above the packer or valve 430, and a further isolating collar 200c mounted below the packer or valve 430. A cable 432 is used to circumvent the packer or valve 430 (or any other obstructing object) using a standard isolated packer penetrator 434.

The slave units 50a, 50b, 50c in this embodiment may be used for reservoir monitoring using pressure and/or temperature sensors, flow meters, and fluid temperature probes. These slave units 50a, 50b, 50c may also be used to operate and control gas lift valves, fluid production intake valves and fluid circulating valves. The slave units 50a, 50b, 50c may also be used to control a packer with a flow through valve controlled from the master unit 10. The telemetry system has the capability to apply substantial electrical power to downhole actuators (not shown) due to the low resistance of the pipe 404

in the tubing string. Thus, the telemetry system can be implemented to drive and control large motors, actuators and the like.

In some downhole applications, fluid in the space between the casing 412 and the outside surface of the production tubing 404 is conductive. In this case, the tubing 404 in addition to being spaced from the casing 412 by the insulating protectors 424, would also be coated with an insulating paint or the like to increase the amount of electrical isolation between the tubing 404 and casing 412.

The telemetry system can tolerate a certain degree of leakage current from the tubing 404 to the casing 412 so that complete coating and full isolation is not a primary requirement. The leakage tolerance is achieved by using telemetry signal levels that have sufficient margin to tolerate this leakage current.

Referring now to Figs 13a and 13b, Fig. 13a shows a subsea pipeline system 500, that includes a dual pipeline 502, 504, and Fig. 13b illustrates a subsea pipeline system 550 that includes a single pipeline 552. In Figs 13a and 13b, the pipelines 502, 504, 552 are typically under water (either fresh or sea water) and the pipelines 502, 504, 552 are used as the power and communications transmission medium for the telemetry system.

The master unit 10 of the telemetry system includes a power supply and master control unit, and is typically located above the water level and before the point where the pipeline 502, 504, 552 enters the water. The pipelines 502, 504, 552 generally do not have any other power source present on the pipelines 502, 504, 552 in such applications, and thus it is not necessary to capacitively couple the master unit 10 to the pipeline 502, 504, 552. Thus, direct coupling of the ac power from the master unit 10 to the pipelines 502, 504, 552 may be used. However, it will be appreciated that capacitive coupling will be required where the pipelines 502, 504, 552 are used to carry any other power source.

A single or two wire connection is made from the master unit 10 to a connection point 504 at or near the isolating collar 200a. At the connection point 504, the live power wire from the master unit 10 is coupled to an isolated portion 502i of the pipeline 502, by making connection to the metallic body of the isolated portion 502i of the pipeline 502. The electrical contact can be made by clamping to the pipeline 502, or using a modified portion of pipe with an electrical connector or coupling fitted thereto, or in any other suitable manner. An isolating tubing collar 200a in the pipeline 502 electrically isolates the pipeline 502 from a source 506 of the transported fluid, and supports the weight or tension in the pipeline 502. A second isolating collar 200b is positioned at or near a delivery end

502d of the pipeline 502. The isolating collars 200a, 200b can be either of an oil field thread type, or may be coupled to the pipeline 502 at the termination of the dual pipe couplings, where the couplings may be modified to suit the pipeline material and coupling method, but the internal structure of the collars 200a, 200b is as described above. It should be noted that either of the isolating collars 200, 300 may be used.

In this way, a transmission zone 502z is defined between the isolating collars 200a, 200b. The master unit 10 is electrically coupled to the transmission zone 502z using the isolating collar 200a, for example, as described above. Slave units 50a, 50b can then be electrically coupled at any point within the transmission zone 502z so that any power and/or data transmissions from the master unit 10 (or data transmissions from the slave units 50a, 50b to the master unit 10) can be retrieved.

The isolated portion 502i of the pipeline 502 is insulated partially from the water by both coating of the pipeline 502 and insulating protectors 510. The coating can be selected from any of a number of available techniques. The insulating coatings typically provide a substantial fluid resistance, and complete water sealing is preferable but not essential. Similarly, at pipe joints under water in the pipeline 502, the joints should be covered with plastic or rubber insulating covers to provide

protection against physical damage, any electrical shorting and also water ingress into the joints. Injection of insulating grease or sealant into the joint covers is again preferable but not necessary.

At any point in the transmission zone 502z, slave units 50a, 50b can be attached to provide monitoring of sensors or control of actuators as described above. Any number of slave units 50 may be coupled into the system as required.

Referring to Fig. 14, the slave units 50a, 50b are typically mounted so that the units 50a, 50b make electrical contact with the live metal of the transmission zone 502z. If the body of the protective pressure housing 426 (Fig. 14) is attached to the metal of the pipe 502, 504, 552 then it will be live and will require an isolated ground contact that is connected to the local ground 554 (Fig. 13b) or second pipeline 504 (Fig. 13a) that are used as ground returns. The ground contact is typically made by attaching a fly lead 436 to one of the insulated end pieces 428, and thus end pieces 428 are typically grounded. The protective pressure housing 426 typically protects the electronics from the water pressure, and additionally isolates the ground contact from the live pipe 502, 504, 552.

The slave units 50 require a ground or earth to complete the electrical circuit. This can be achieved using local grounding 554 such as the

seabed, a lake bed or the like, schematically illustrated in Fig. 13b. Alternatively, this may also be achieved by using another pipeline 504 running next to the "live" one as the ground return, schematically illustrated in Fig. 13a.

The slave unit 50 located underwater can have several functions including strain gauge measurement on pipeline stress, lifting forces from riser buoyancy elements, fluid temperature measurement, flow rate measurement in co-mingled lines, or the like. Further uses could be to provide control of a subsea installed wellheads using the underwater pipeline as the only power and communications medium. The functionality of the slave unit 50 could include the control of wellhead actuators, measurement of choke positions and measurement of local pressure and temperatures.

A further use of this system would include coupling an underwater acoustic modem to the slave unit 50 to allow interrogation of long pipeline sensor systems from floating rigs, FPSO and ships while working on the pipe line 502, 504, 552 or associated systems.

Referring now to Figs 15a and 15b, there is shown a dual and single pipeline system 600, 650 respectively, that are typically located on the surface. The master unit 10 includes a power supply and master control unit and is typically located near the source 610 of the pipeline 602, 604, 650, or

coupled to the pipeline 602, 604, 652 using a suitable cable. An isolating tubing collar 200a is coupled into the pipeline 602, 652 to isolate the pipe 602, 652 from the source 606 of the transported fluid, and support the pipeline 602, 652. In addition, there is a second isolating collar 200b positioned at the delivery end 602d, 652d of the pipeline 602, 652. Either isolating collar 200 or collar 300 may be used.

The live or power line from the master unit 10 is coupled to an isolated section 602i, 652i of the pipeline 602, 652 using a clamp or connector to attach to the steel of the pipeline 602, 652, similar to the embodiments shown in Figs 13a and 13b. The isolated section 602i, 652i of the pipeline 602, 652 is insulated partially from the weather and/or the surrounding surface by both coating of the pipeline 602, 652 and insulating protectors 610. The coating and insulating joint protectors 610 typically provide a substantially water-tight cover. It is not a requirement that the coating and protectors 610 are completely water-tight.

In this way, a transmission zone 602z is defined between the isolating collars 200a, 200b. The master unit 10 is electrically coupled to the transmission zone 602z using the isolating collar 200a, for example, as described above. Slave units 50a, 50b can then be electrically coupled at any point within the transmission zone 602z so that any power and/or

data transmissions from the master unit 10 (or data transmissions from the slave units 50a, 50b to the master unit 10) can be retrieved

Where the pipeline 602, 652 is on the surface, the pipeline 602, 652 is supported along its length by insulating supports (not shown) to prevent it from grounding to earth. These supports are typically fabricated from standard supports with isolating rings to space the mounting from the pipeline 602, 652.

As before, a slave unit 50 can be coupled to the transmission zone 602z, 652z at any point along its length, and multiple slave units 50 may be used. Slave units 50a, 50b can be coupled to the transmission zone 602z, 652z to provide monitoring of sensors or control of actuators, as described above.

Referring now to Fig. 16, the slave units 50a, 50b would typically be mounted on a grounded structure (not shown) around the pipeline 602, 652 and a single wire 620 run to a clamp 622 or connector connecting the slave unit 50a, 50b live connect to the metal of the pipeline 602, 652.

The slave units 50 require a ground or earth to complete the electrical circuit. This can be achieved by either using local grounding 624 like the earth (schematically illustrated in Figs 15b and 16), or may also be achieved by using another pipeline 604

running next to the "live" one as the ground return (as illustrated in Figs 15a and 16).

The slave unit 50 can perform a plurality of functions in relation to a surface pipeline 602, 652, such as fluid flow measurement, valve control, pipe corrosion or strain measurement, fluid composition measurement, pressure, temperature, vibration and also pipe inclination for subsidence monitoring. Shut down valves could also be driven from a slave unit 50 as well as control of pumps and drain or bleed valves to control fluid pumping or control equipment remotely using the pipeline 602, 652 as the control link.

This particular embodiment is useful for controlling remote pumping stations where the station is far removed from electrical power and/or telephone lines. The telemetry system can provide both power to the pumps, and also the ability to measure and control the pumping operation.

Fig. 17 illustrates a surface pipeline comprising first and second isolated pipelines 702, 704 (similar to the system shown in Figs 13a, 13b), and an isolated subsea or downhole tubing 706 (similar to the system shown in Fig. 9). An oilwell 708 which has a wellhead 712 on the surface has the isolated pipelines 702, 704 coupled thereto from the surface, and on the same system has the isolated downhole production tubing 706 suspended therebelow.

The pipeline 702 from the surface is isolated with an isolating tubing collar 200a at the surface, and a second isolating collar 200b is provided at or near the wellhead 712, creating a transmission zone therebetween. An electrical link 714 couples the power and data transmissions from the isolated supply from the surface pipeline 702 to a wellhead penetrator 716 and this in turn couples the power and data transmissions to the isolated downhole tubing 706. The downhole tubing 706 typically has at least one slave unit 50 coupled thereto (Fig. 17 shows two slave units 50a, 50b) that are connected back to electrical ground through the downhole casing 718. As before, slave units 50c and 50d can be coupled anywhere in the isolated transmission zone of the surface pipeline 702, or the downhole tubing 706. The slave units 50c, 50d may use the second pipeline 704 as a ground return, or may be grounded locally, depending upon the application and/or the location of the slave units 50c, 50d.

A further extension of this system would be to use a single subsea pipeline (not shown) to couple several downhole wells together on the same system. This would also apply where the oilwell had multi-lateral bore holes and each arm of the multi-lateral system was both isolated and connected to the same power source. The system would have the ability to supply substantial levels of power to drive the electronics

and controls at each of the wells that are coupled to the slave units 50.

Thus, there is provided a telemetry system that in certain embodiments allows for both power and data transmissions across an isolated tubing string or pipeline. The system in certain embodiments uses frequency-shift keying (FSK) and pulse-width modulation to allow for the transmission of data across the pipeline or tubing string.

The system in certain embodiments is flexible in that it allows for a number of slave units to be located remotely from one or more master units, the master units being used to control the operation of the slave units. The slave and master units are typically coupled to a single transmission medium, such as the isolated pipeline or tubing string. The system in certain embodiments can also support the use of more than one master unit to control the slave units from more than one point within the system.

There is also provided a method of transmitting pulse-width modulated power over an isolated pipeline or tubing string and recovering this as both power and data. There is also provided a method of transmitting frequency-shifted data that is synchronised to a received power waveform.

Modifications and improvements may be made to the foregoing, without departing from the scope of the present invention.

CLAIMS

1. A telemetry system comprising a master unit, and at least one slave unit remote from the master unit, the master and slave units communicating via a transmission system, wherein the telemetry system is capable of transmitting power and data transmissions between the units, and wherein the transmission system includes an at least partially isolated tubing string or pipeline.

2. A telemetry system according to claim 1, wherein the pipeline or tubing string is electrically isolated using at least one isolating collar.

3. A telemetry system according to claim 2, wherein the isolating collar comprises first and second connectors, the first and second connectors being threadedly coupled together.

4. A telemetry system according to claim 3, wherein an electrical isolating material is injected between the first and second connectors to isolate the connectors from one another.

5. A telemetry system according to claim 3 or claim 4, wherein the isolating collar includes means for conveying electrical signals from outwith the collar to the second connector.

6. A telemetry system according to any preceding claim, wherein the pipeline or tubing string is

coated with an electrically isolating coating to at least partially isolate the pipeline or tubing string.

7. A telemetry system according to any preceding claim, wherein the at least partially isolated pipeline or tubing string comprises a surface pipeline or tubing string.

8. A telemetry system according to any one of claims 1 to 7, wherein the at least partially isolated pipeline or tubing string comprises a subsea pipeline or tubing string, or a downhole pipeline or tubing string.

9. A telemetry system according to any preceding claim, wherein the at least partially isolated pipeline or tubing string comprises any combination of surface, subsea or downhole pipelines or tubing strings.

10. A telemetry system according to any preceding claim, wherein the pipeline or tubing string includes a first isolating collar at or near a source of fluid flowing within the pipeline or tubing string.

11. A telemetry system according to claim 10, wherein the pipeline or tubing string includes a second isolating collar at or near a sink for the fluid in the pipeline or tubing string.

12. A telemetry system according to claim 10 or claim 11, wherein the master unit is electrically coupled to the pipeline or tubing string via the first isolating collar.

13. A telemetry system according to any preceding claim, wherein at least one slave unit is coupled to the pipeline or tubing string.

14. A telemetry system according to any preceding claim, wherein the slave unit comprises a mandrel, a slave module, and an electrical return path.

15. A telemetry system according to claim 14, wherein the mandrel facilitates attachment of the slave unit to the pipeline or tubing string.

16. A telemetry system according to claim 14 or claim 15, wherein the mandrel facilitates transmission of the electrical power and data transmissions from the pipeline or tubing string to the electronics of the slave unit.

17. A telemetry system according to any one of claims 14 to 16, wherein the slave module houses the electronics of the slave unit.

18. A telemetry system according to any one of claims 14 to 17, wherein the electrical return path comprises a spring contact for engaging an earth point.

19. A telemetry system according to claim 18, wherein the earth point is a local earth, a further tubular such as a second pipeline, a subsea or surface casing, or a casing of a downhole well.

20. A telemetry system according to any preceding claim, wherein pulse-width modulation is used to facilitate data transmission from the master unit to the slave unit.

21. A telemetry system according to claim 20, wherein the power transmission is modulated with the data transmission using pulse-width modulation.

22. A telemetry system according to any preceding claim, wherein frequency-shift keying (FSK) is used to facilitate data transmission from the slave unit to the master unit.

23. A telemetry system according to claim 22, wherein the FSK frequencies are superimposed on a carrier frequency.

24. A telemetry system according to claim 23, wherein the carrier frequency is the same frequency as the power transmission frequency.

25. A telemetry system according to any one of claims 22 to 24, wherein the data transmission is

synchronised to the "high" cycle of the power transmission.

26. A telemetry system according to any one of claims 22 to 25, wherein the data transmission is synchronised to the "low" cycle of the power transmission.

27. A telemetry system according to any one of claims 22 to 26, wherein the data transmission is synchronised to both the high and the low cycles of the power transmission.

28. A telemetry system according to any preceding claim, wherein more than one slave unit is used.

29. A telemetry system according to claim 28, wherein the data transmission from the master unit to the slave unit includes an address of the slave unit.

30. A telemetry system according to claim 29, wherein the data transmissions include data error detection and/or correction.

31. A telemetry system according to claim 30, wherein the data error detection and/or correction comprises a Hamming code.

32. A telemetry system according to any preceding claim, wherein the master unit comprises a processor to control the operation of the master unit; a power

waveform generator; and signal recovery and conditioning circuitry.

33. A telemetry system according to claim 32, wherein the processor applies pulse-width modulation to the power transmission when data transmission is required from the master unit to the slave unit.

34. A telemetry system according to claim 32 or claim 33, wherein when not transmitting data, the processor defaults the power transmission to a 50% duty cycle.

35. A telemetry system according to any one of claims 32 to 34, wherein the signal recovery and conditioning circuitry allows data transmitted by the at least one slave unit to be extracted and recovered from the transmission system.

36. A telemetry system according to any preceding claim, wherein the slave unit comprises a processor to control the operation of the slave unit; rectifying and regulating circuitry in a first channel; recovery and conditioning circuitry in a second channel; and frequency generating and mixing means.

37. A telemetry system according to claim 36, wherein the frequency mixing and generating means typically comprises a frequency-shift keying (FSK) generator; an FSK mixer; and a line driver.

38. A method of transmitting power and data from a master unit to at least one slave unit remote from the master unit, the master and slave units communicating via a transmission system, the transmission system including an at least partially isolated pipeline or tubing string, the method comprising the steps of

generating a power transmission at the master unit;

generating a data transmission and synchronising the data transmission with the power transmission at the master unit;

transmitting the power and data transmissions via the transmission system to the slave unit; and

recovering the power and data transmissions at the slave unit.

39. A method of transmitting data to a master unit from at least one slave unit remote from the master unit, the master and slave units communicating via a transmission system, the transmission system including an at least partially isolated tubing string or pipeline, the method comprising the steps of

generating a power transmission at the master unit and transmitting the power transmission to the slave unit;

recovering the power transmission at the slave unit;

generating a data transmission at the slave unit and synchronising the data transmission with the power transmission;

transmitting the data transmission via the transmission system to the master unit; and

recovering the data transmission at the master unit.

40. A method according to either claim 38 or claim 39, wherein the method includes the further steps of

dividing the data transmission into a series of sub-windows;

transmitting a specified data transmission from the slave unit to the master unit;

receiving the specified data transmission at the master unit;

determining which of the sub-windows reliably transmitted the specified data transmission.

41. A method according to claim 40, wherein the sub-windows that did not reliably transmit data are filtered out or ignored for subsequent transmissions.

42. A method of receiving and converting power and data transmissions sent from a master unit to at least one slave unit remote from the master unit, the master and slave units communicating via a transmission system, the transmission system including an at least partially isolated pipeline or tubing string, the method comprising the steps of

receiving a power transmission at the slave unit;

dividing the power transmission into two channels;

rectifying and regulating the power transmission in a first channel; and

recovering the data transmission in a second channel.

43. A method of receiving data transmitted by a master unit from at least one slave unit remote from the master unit, the master and slave units communicating via a transmission system, the transmission system including an at least partially isolated pipeline or tubing string, the method comprising the steps of

receiving the data transmission at the master unit;

filtering and conditioning the data transmission; and

regenerating the transmitted data.

44. A method according to either claim 42 or claim 43, wherein the method includes the further steps of

dividing the data transmission into a series of sub-windows;

transmitting a specified data transmission from the slave unit to the master unit;

receiving the specified data transmission at the master unit;

determining which of the sub-windows reliably transmitted the specified data transmission.

45. A method according to claim 44, wherein the sub-windows that did not reliably transmit data are ignored or filtered out for subsequent transmissions.

46. A method according to any one of claims 38 to 45, wherein pulse-width modulation is used to facilitate data transmission from the master unit to the slave unit or vice versa.

47. A method according to claim 46, wherein the power transmission is modulated with the data transmission using pulse-width modulation.

48. A method according to any one of claims 38 to 47, wherein frequency-shift keying (FSK) is used to facilitate data transmission from the slave unit to the master unit or vice versa.

49. A method according to claim 48, wherein the FSK frequencies are superimposed on a carrier frequency.

50. A method according to claim 49, wherein the carrier frequency is the same frequency as the power transmission frequency.

51. A method according to any one of claims 38 to 50, wherein the data transmission is synchronised to the "high" cycle of the power transmission.

52. A method according to any one of claims 38 to 51, wherein the data transmission is synchronised to the "low" cycle of the power transmission.

53. A method according to any one of claims 38 to 52, wherein the data transmission is synchronised to both the low and high cycles of the power transmission.

54. A method according to any one of claims 38 to 53, wherein the data transmissions include data error detection and/or correction.

55. A method according to claim 54, wherein the data error detection and/or correction comprises a Hamming code, or other suitable technique.

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Claims searched:	1-42 at least	**Date of search:**	13 November 2000

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H4R (RTC,RTR,RTSR,RTSU,RTT); E1F (FHK)

Int Cl (Ed.7): H04B (3/54); E21B (47/12); G08C

Other: Online: EPODOC,WPI,JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X,P	GB 2338253 A	(Schlumberger) see e.g. fig 4	1,6,8,9, 13,28
X,Y	GB 2180574 A	(Camco) see especially page 2, lines 8-10	1,8,13
Y	GB 2083321 A	(Marconi) see especially page 1, lines 115-127	28
Y	EP 0381802 A	(Eastman Christensen) see especially fig 4 and col 13, lines 35-37	22
Y	US 4861074 A	(Production Technologies) see fig 2	2-5,10,12
Y	US 4716960 A	(Production Technologies) see fig 3	2-5,10,12

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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